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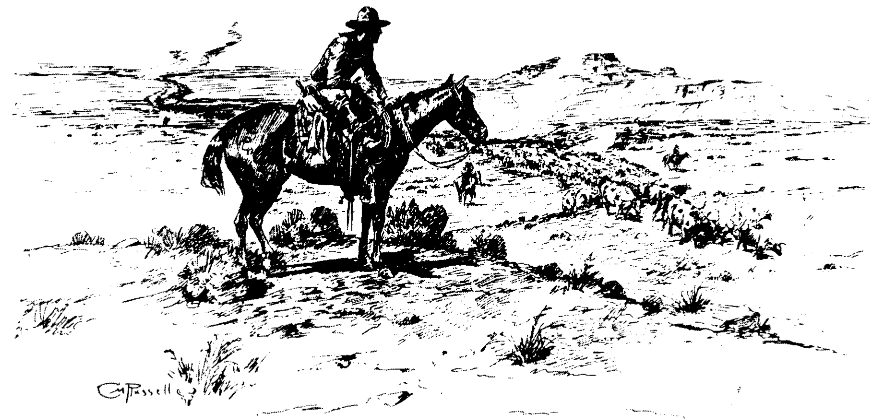

THE TRAIL BOSS

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Low-Level Aerial Photography as a Management and Research Tool for Range Inventory

T.W. HEINTZ, J.K. LEWIS, AND S.S. WALLER

Abstract

An inexpensive technique is reviewed for using low-level aerial photography as a management and research tool for range. Modifications of a previously documented camera mount are reported that allow greater flexibility in the use of aerial photography for range evaluation. This technique involves the use of color infrared film with a 135-mm telephoto lens double filtered with orange and magenta filters.

As increasing demands are placed on our private and public rangelands, care must be taken to manage these valuable resources in such a way as to maintain them in a productive condition. To manage rangelands properly, records of annual vegetative changes should be maintained and evaluated. Vegetation samples are usually clipped to provide records for documenting changes in vegetation. This requires a substantial amount of labor, time, and money. Collecting information about changes in vegetation utilizing low-level aerial photography can reduce time, labor, and expense.

Aerial photographs from a light plane can be obtained rapidly with a minimum amount of labor. These photographs contain valuable information that can be used for managing private and public lands, and for range research purposes. Many agencies already have the necessary equipment at their disposal for collecting aerial photographs. The Bureau of Land Management in Montana has used a 35-mm aerial photography system for several years (Meyer and Gerbig 1974). This method of data collection enabled them to inventory study plots more rapidly than from the ground. Small format (35-mm) aerial photography from light aircraft has great potential as part of a coordinated system of range inventory. Aerial photographs of the same area at different times during the year and from year to year can provide information on patterns of growth and utilization of range vegetation, vegetative change, range condition, and occurrence of biotic disturbance as well as an overall view of the area.

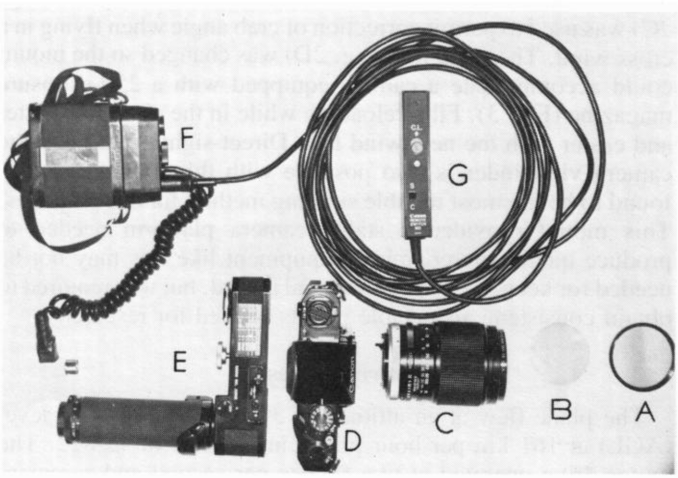

Fig. 1. *Camera set up with a Tiffen 15 orange filter (A), Kodak magenta filter (B), Canon 135 mm telephoto lens (C), Canon F-1 (D), Canon motor drive (E), Canon power pack (F) with remote switch (G).*

Part of the range research at South Dakota State University uses low-level aerial photography to obtain high-quality infrared stereograms in 35-mm format. These pictures are used for determining sample collection programs and maintaining a pictorial record of vegetation on experimental ranges at the Range and Livestock Experiment Station, Cottonwood, South Dakota.

Equipment

Photographs were collected using a 35-mm Canon[1] F-1 camera equipped with a motor drive and a 135-mm telephoto filtered with Tiffen 15 orange and Kodak magenta filters (Fig. 1). A camera mount using the same basic design of Meyer (1973) was built by university personnel to fit light, high-wing aircraft (Fig. 2). Various modifications were made to improve the mount. The base unit (Fig. 2B), which fastens to the door of the plane, was modified to make the mount usable on tandem aircraft with conventional landing gear that can operate from

Authors are research technician, associate professor, and assistant professor, respectively, Animal Science Department, South Dakota State University, Brookings, S.D. [illegible]. Mr. Heintz is currently employed as a range conservationist with the Forest Service at Wisdom, Montana, and S.S. Waller is presently associate professor, Department of Agronomy, University of Nebraska, Lincoln NE 68583.

This report is approved for publication by the Director of South Dakota Agricultural Experiment Station as Publication No. 1560 of the Journal Series.

The authors extend their appreciation to Roy V. Muchow, South Dakota State University Engineering Shop, for the design and construction of the camera mount used in this study.

Manuscript received April 24, 1978.

[1] Mention of product names in this paper does not constitute a recommendation by the South Dakota Agricultural Experiment Station.

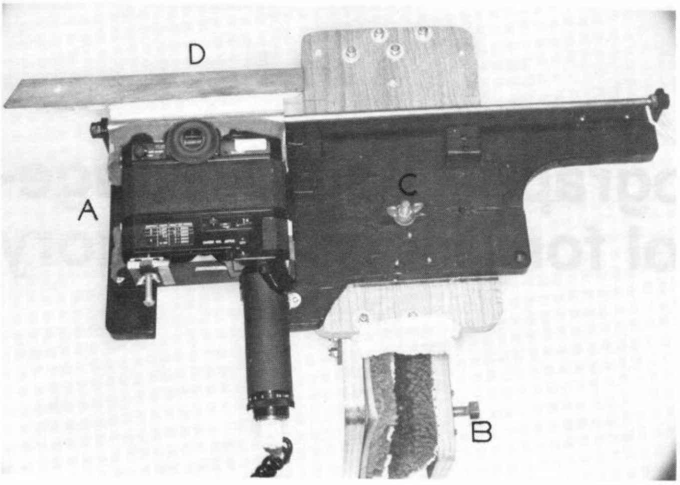

Fig. 2. *Camera with 36-exposure magazine (A) attached to the camera mount. The camera mount attaches to the door of the airplane with the window in the up position by a cushioned clamp base unit (B). [Note the center pivot-point (C) and the wind foil (D)].*

rough or nonexistent landing fields. A center pivot-point (Fig. 2C) was used to permit correction of crab angle when flying in a cross wind. The wind foil (Fig. 2D) was changed so the mount could accommodate a camera equipped with a 250-exposure magazine (Fig. 3). Film reloading while in the air is also faster and easier with the new wind foil. Direct-sighting through the camera viewfinder is also possible with this mount and was found to be the most reliable sighting method for our purposes. This mount provided a stable camera platform needed to produce quality stereograms. Equipment like this may not be needed for keeping a yearly pictorial record, but was required to obtain consistent, repeatable results needed for research.

Procedures

The plane flew at an altitude of 381 m above ground level (AGL) at 161 km per hour producing a scale of 1:2822. The motor drive operated at two frames per second and a camera shutter speed of 1/500 second was used. This provided approximately 50% overlap of consecutive frames for stereo coverage. Color infrared Ektachrome film was used, with a combination of both Tiffen 15 orange and Kodak magenta filters attached to the lens.

Color infrared film was used because it provided more information than color Ektachrome. Living vegetation was easily distinguished on the infrared film and changes in vegetation throughout the growing season could be more easily documented. Live vegetation appeared as shades of red and dead plant material as shades of green when color infrared pictures were taken with the orange and magenta filters.

The color infrared film was processed in a field laboratory at the Range and Livestock Experiment Station. This was accomplished by converting part of the laboratory into a darkroom, using a controlled-temperature waterbath, Kodak E-4 color processing kits, Kodak color control processing strips, and Durst developing equipment. Film was removed from the film cartridge within a Burke and James changing bag and put into a light-tight developing canister, eliminating the need for a total darkroom. Actual processing time in the developing tank was 55 minutes. The total procedure required about 70 minutes, including time for getting the film onto the reels and into the developing tank, developing the film, wiping the film, and hanging it up to dry. The result was high-quality imagery that exhibited remarkable detail.

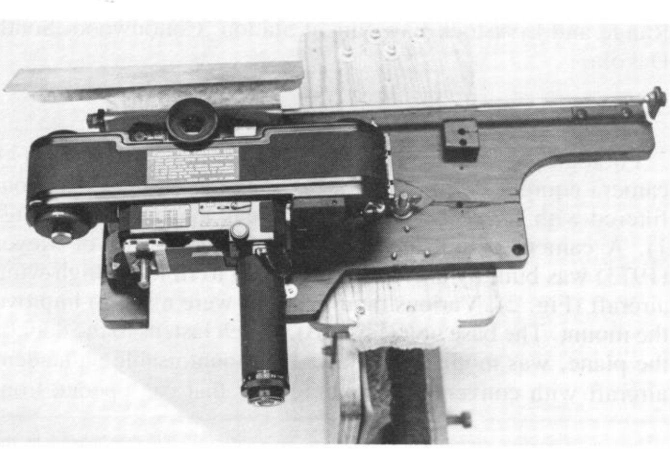

Fig. 3. *Camera with a 250-exposure magazine attached to the camera mount.*

Problems

Problems encountered with this method of data collection are many and varied, but can be solved with experience and practice. The weather in South Dakota is especially unpredictable. One can never pick a day in advance to take pictures from a light aircraft. Cloud conditions are often quite variable, and winds are often too gusty for a small plane to fly in a precise line. Consequently, a pilot and airplane with a flexible schedule are needed.

Reliable camera equipment is a necessity. A dependable system that gives consistent results is required, particularly in research work. Valuable time and money may be lost if inferior equipment is used. Thus, the most economical camera for such a job may be one of the more expensive, but highly dependable, models.

Color infrared film was available only in twenty exposure rolls making reloading film while in the air a necessity in our operation. This presented certain hazards. When the camera was in the operating position outside the plane, it was buffeted by a substantial blast of air. Thus, a camera mount that allowed the camera to be brought inside the airplane was needed for removing and loading film. Empty and loose film canisters rolling around the floor of the plane also made it difficult to maintain an organized process. This problem was solved by taping film canisters together into a belt and numbering them. The lens was taped at infinity to prevent it from being accidentally turned out of focus.

The major problem encountered in flying relatively low-level aerial photography in a light plane was marking the area so that it could be seen easily from the air and then lining up and staying on the flight line to achieve accurate, repeatable coverage. This problem was solved by marking the flight lines with white planks and numbering them with formations of white painted rocks. The rock formations were 1.83 m in length and planks were 3.05-3.66 m long and 25.4 cm wide. The white markers stood out well and were easy to see from a distance (Fig. 4).

In order to stay on the flight lines, the photographer leaned out of the airplane and looked through the camera viewfinder. This gave the photographer the opportunity to check the camera setting immediately before shooting and to start the motor drive at the proper time. This also gave the photographer the option of not shooting if the plane was not properly lined up, or if it was blown off target at the last minute. A periscope was constructed which was mounted on the camera mount and allowed the

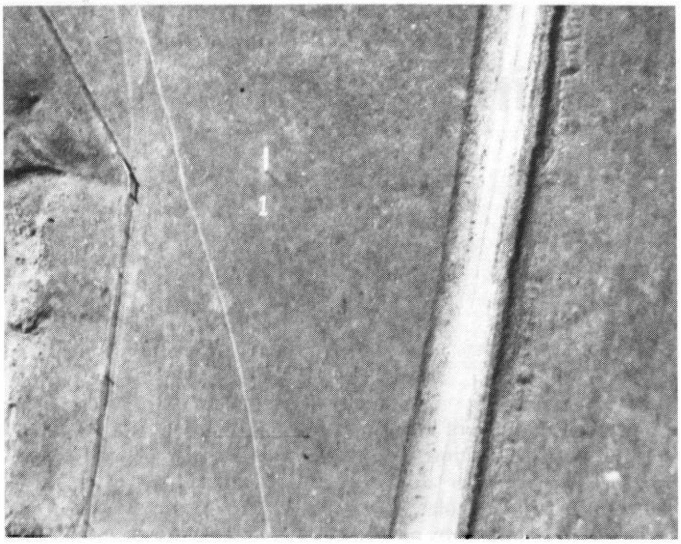

Fig. 4. *Aerial photo (scale 1 cm=4.1m) taken from 381 m above ground level with 135-mm telephoto lens (Note: number 1 formed with white rocks and white planks identifying the flight line).*

operator to view the flight line from the rear seat of the airplane. However, direct observation through the viewfinder was found to be the most foolproof sighting method available for use with the removable outside mount. Goggles were necessary to protect the photographer's eyes.

Use of Imagery

Imagery from this system was used to delineate soil and vegetation patterns and to stratify clip-plot locations in range research projects. Stratification of clip-plot locations on a solodized-solonetz soil complex near Rapid City using low-level aerial photography reduced the number of samples needed for sampling weight of western wheatgrass (*Agropyron smithii;* Beetle 1970, Van Bruggen 1976)[2] to within 10% of the mean with 95% probability from 430 to 30 plots (Waller et al. 1978). This resulted in a great saving of time, labor, and money.

Also, pictures were taken along permanent flight lines located in the experimental pastures at Cottonwood. These flight lines ranged from 182 m to 914 m in length and were located on key use areas in low, medium, and high range condition. Pictures were taken monthly during the growing season in 1976 and 1977 in conjunction with color infrared stereograms taken from a height of about 1 m supplemented with clip-plot information. This imagery was taken as part of a range ecosystem inventory method which is being developed.

[2] Nomenclature follows Beetle (1970) for common name and Van Bruggen (1976) for scientific name.

Costs

The cost of this method of data collection was relatively low after the initial purchase of the camera system. About $900 was invested in the camera, lens, and motor drive, with the mount costing $60 and developing equipment $60. Airplane expense was $31 per hour, film $2.75 per roll, and processing chemicals about $1.20 per roll. Labor costs must also be included for the photographer and film processor. When comparing these costs to those incurred when using larger format (small-scale photography) aerial photography, such as that from a remote sensing agency, the method described in this article is a very economical method of data collection. One routine photo mission flown over the Range and Livestock Experiment Station by the nearest remote sensing agency would have cost over $1,100. The cash cost of one mission with nearby light aircraft was only $70. Thus, the saving derived from the first mission was sufficient to more than offset the cost of all the photographic equipment. Not only is this system economical, but it also possesses outstanding flexibility with regard to flight time and film processing, which is extremely important in a region with variable weather.

Summary

Land managers need a fast, reliable, inexpensive method of gathering information to wisely manage their resource. Photography from light aircraft can partially replace traditional labor-intensive information gathering methods and holds great promise for the future.

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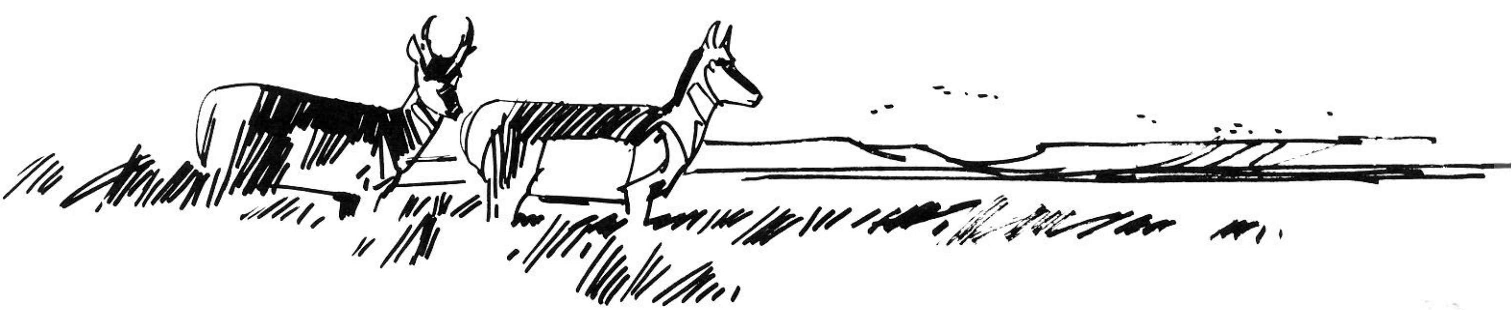

Herbage Response to Grazing Systems and Stocking Intensities

H. WALT VAN POOLLEN AND JOHN R. LACEY

Abstract

A review of pertinent literature shows that grazing systems and grazing intensities both influence herbage production on Western ranges. Mean annual herbage production increased by 13% when grazing systems were implemented at a moderate stocking intensity. Increases were larger (35% and 27%) when continuous livestock use was reduced from heavy to moderate, and moderate to light, respectively. This suggests that adjustments in livestock numbers have a greater effect on herbage production than do grazing systems.

Grazing systems are being implemented on Western ranges by land management agencies. These agencies use studies by Hormay and Talbot 1961, Hormay and Evanko 1958, Merrill 1954, Reardon and Merrill 1976, Martin 1973, and Hickey and Garcia 1964, among others, to support this action. These grazing system studies report better livestock distribution, greater herbage and livestock production, and improved range condition. However, literature reviews (Hickey 1968; Heady 1961; Herbel 1971; and Shiflet and Heady 1971) also summarize grazing system studies which report nonsignificant forage responses, reductions in livestock production, and cost increases. Some researchers (Heady 1961; Mathis and Kothmann 1968; Cook 1966; and McMeekan 1956) feel that vegetation is affected more by grazing intensity than by grazing systems.

One objective of this paper is to review and analyze data from grazing system and grazing intensity studies. The second objective is to determine whether livestock adjustments have a greater effect on herbage production than do grazing systems.

Methods

We have compared specialized grazing systems to continuous grazing. Heady (1961) treated rotation, deferred, rest rotation, and deferred rotation systems as specialized systems and considered seasonlong and yearlong grazing to be continuous use. This approach is logical because differences between vegetative types and periods of use and nonuse make it difficult to compare one specialized system to another.

Herbage production data are the most reliable measure of grazing management procedures (Klipple 1964). Consequently, grazing studies were reviewed to find those which compared herbage production data under continuous use and specialized grazing systems. Results were used only from studies describing use at a moderate level (40-60%). Herbage production under the respective systems was tabulated from each of 18 studies and the difference in productiveness between the grazing systems and continuous are determined. An average difference for all studies was calculated. An average difference was also calculated for the four geographic regions. These means were compared by an analysis of variance. We have used these average differences as a measure of the vegetal response that can be expected when a specialized grazing system is implemented.

Differences in herbage production under light, moderate, and heavy livestock use were also tabulated from 14 studies. Results were used only from studies describing use at a comparable level as follows: heavy, 60-80%; moderate, 40-60%; and light 20-40%. Average differences between production at the three use levels were calculated. An average difference was also calculated for two geographic regions. These means were compared by an analysis of variance. We have used these average differences as a measure of the vegetal response which can be expected when livestock use is reduced from heavy to moderate, and from moderate to light, respectively.

Results and Discussion

Herbage Response to Grazing Systems

Herbage production averaged 13% higher when livestock use was controlled by a specialized grazing system, rather than being continuous (Table 1). Two of the studies (Hamilton et al.

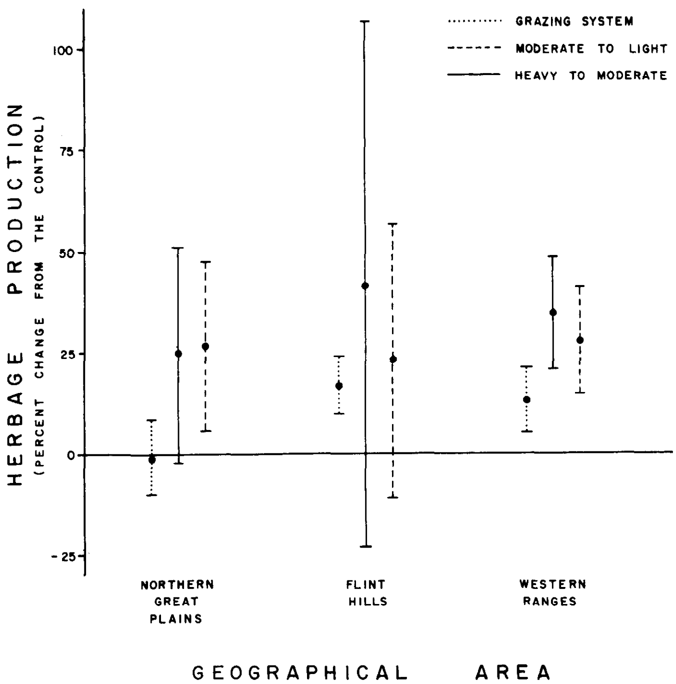

Fig. 1. *Herbage production response for three geographical areas under different grazing intensities (heavy to moderate, moderate to light and under grazing systems. Nodes represent means and confidence intervals at 95%.*

Both authors were employed by the Bureau of Land Management as range conservationists, in Socorro New Mexico. Van Poollen is now at the Department of Agricultural Economics, Univ. of Hawaii, Honolulu, and Lacey is at the Department of Range Science, Utah State University, Logan.

The authors wish to thank Dr. Robert P. Gibbens and Dr. Pat O. Currie for their helpful reviews.

Manuscript received May 10, 1978.

Table 1. Herbage production (lb/acre) under grazing systems and continuous use, and mean differences in production for 18 studies in 6 geographical areas.

Author Geographic Area	Production: Grazing System	Production: Continuous Use	Percentage difference
Northern Great Plains			
Black et al. 1937	—No difference—		0
Black et al. 1942	—No difference—		0
Campbell 1961	1350	1163	16
Hubbard 1951		Higher	−12
Lodge 1970	−301	−261	−13
Smoliak 1960	489	465	5
			$\bar{X}=-.7\%, S=11, S\bar{x}=4$*
Flint Hills			
Herbel et al. 1959			
Ordinary upland	1952	1744	12
Limestone breaks	1996	1499	33
Clay upland	1346	1116	21
Owensby et al. 1973			
Loamy upland	4521	4218	7
Breaks	3564	2898	23
Clay upland	4311	3657	18
Smith et al., 1978	2759	2604	6
			$\bar{X}=17, S=10, S\bar{x}=4$*
Texas			
Kothmann et al. 1975			
Deep upland	1532	1233	24
Deep upland	1227	955	28
Rolling hills	1287	723	39
Rolling hills	1054	788	34
Keng et al. 1960	Higher		25
Reardon et al. 1976	1188	481	147**
			$\bar{X}=30, S=6, S\bar{x}3$*
Southwest			
Martin 1970	220	550	−60
Martin 1973	89	64	39
Martin el al. 1976			
Site I	551	394	47
Site II	195	175	11
Site III	357	387	−8
			$\bar{X}=6, S=61, S\bar{x}=27$*
Pacific Northwest			
Hamilton 1945	Higher		9
Skovlin et al. 1976			
Grassland	+51	+21	143**
Forest	−108	−134	19**
Colorado			
Klipple 1964	−298	−35	−750**
Average for Western Ranges			$\bar{X}=13, S=23, S\bar{x}=5$*

Confidence interval of the mean was calculated at a 95% level.
Treated as outliers, and not included in the analysis.

Table 2. Herbage Production (lb/acre) under two grazing intensities and mean differences in production for 14 studies in 9 geographic areas.

Author	Production: Heavy	Production: Moderate	% Change
Northern Great Plains			
Hanson et al. 1970	1752	2092	19
Johnson et al. 1951	1262	1571	25
Lewis et al. 1956			
Ridges	1069	1009	−6
South slopes	1098	1300	19
North slopes	1188	1343	13
Draw	2509	2231	−11
Rauzi 1963	727	1574	117
Reed et al. 1961	314	381	21
			$\bar{X}=25\%, S=40, S\bar{x}14$***
Flint Hills			
Herbel et al. 1959			
Ord. upland	1318	1749	33
Limestone break	1528	1499	−2
Clay upland	505	1116	121
Launchbaugh 1957	1096	1245	14
			$\bar{X}=42\%, S=55, S\bar{x}=28$***
Colorado Seeded Range			
Currie et al. 1970			
Agropyron cristatum	1082	1270	17
Bromus inermis	555	755	36
Ager and Brin	1189	1578	33
Agropyron intermedium	477	894	87
			$\bar{X}=43\%, S=30, S\bar{x}=15$***
New Mexico			
Valentine 1970	49	77	57
Oklahoma			
Hazell 1967	3172	3767	19
Colorado			
Smith 1967	−203	+85	142*
Wyoming			
Pond 1961			
Granitic soil	.48	.74	54**
Sedimentary soil	1.18	1.48	25**
Utah			
Cook 1971	−45%	−11%	76
Pacific Northwest			
Skovlin et al., 1976			
Grassland	+9	+57	533*
Forest	−122	−128	−5
Average for Western Ranges			$\bar{X}=35\%, S=37, S\bar{x}=8$***

Treated as outliers, and not included in the analysis.
Measured in grams per plant.
Confidence interval of the mean was calculated at a 95% level.

1945; and Campbell 1961) investigated tame pastures, the remainder native ranges. Reardon and Merrill's (1976) study was omitted from the analysis because the continuous use pasture was grazed at a higher stocking intensity. The study of Skovlin et al. (1976) was omitted because utilization averaged 26% for the five key species. Klipple's (1964) datum was omitted because it was a statistical outlier (Li 1964).

Herbage response to grazing systems differed by geographical area (Table 1, Fig. 1). For example, when herbage response under specialized grazing systems was compared to that under continuous use, mean herbage production decreased 0.7±9%, increased 17±7%, and increased 30±6% in the Northern Great Plains, Flint Hills, and Texas, respectively. The three studies (Martin 1970; Martin 1973; Martin and Ward 1976) from southern Arizona suggest that mean herbage response will increase by 6±41% when grazing systems are implemented in the Southwest. It is unrealistic to predict mean herbage responses in the shortgrass prairie of Colorado or the Pacific

Northwest because of the restricted number of studies. The analysis of variance showed the means were not significantly different. However, Table 1 suggests that responses in the Flint Hills and Texas regions are similar, and that these are different from the responses in the Northern Great Plains. The data also suggest that additional research is needed in the Southwest before geographic differences can be fully analyzed.

Variation measured on different range sites at or near the Santa Rita Experimental Range (Martin and Ward 1976); in the Flint Hills region (Herbel and Anderson 1959); and in the Texas region (Kothmann et al. 1975) is similar to the variability between geographical regions. Therefore, the 13±8% increase is a realistic estimate of mean herbage response to grazing systems on Western ranges.

Herbage Response to Grazing Intensity

Herbage responses are fairly consistent when livestock numbers are reduced on Western ranges (Tables 2 and 3). Mean herbage production increases 35 and 28% when use is reduced from heavy to moderate, and from moderate to light, respectively. Currie and Smith (1970) studied seeded pastures, the remainder native ranges. Cook's (1971) study was omitted from the analysis because he used a clipping technique to simulate livestock grazing on seven plant species. Data from Smith (1967) and Skovlin et al. (1976) were not analyzed because their utilization levels were lighter than those considered in this analysis.

Only two geographic regions had enough studies to permit comparison on native ranges (Fig. 1, Tables 2 and 3). The analysis of variance showed no significant difference. However, the response from reducing livestock use from heavy to moderate in the Flint Hills (42±65%) was higher than it was in the Northern Great Plains (25±27%). But the response from reducing livestock use from moderate to light was greater in the Northern Great Plains than in the Flint Hills. The differential response may reflect the interplay of short-, mid-, and tall-grass species.

Variation between range sites measured in South Dakota (Lewis et al. 1956) and in the Flint Hills (Herbel and Anderson 1959) is similar to the variability between geographical regions. Therefore, the 35±14%, and the 28±13% increases are realistic estimates of mean herbage response to livestock adjustments that reduce use from heavy to moderate, and moderate to light, respectively.

Table 3. Herbage production (lb/acre) under two grazing intensities a[nd] mean differences in production for 12 studies in 8 geographic area[s]

Author	Production: Moderate	Production: Light	% Change
Northern Great Plains			
Hanson et al. 1970	2092	3700	77
Johnson et al. 1951	1571	2046	30
Lewis et al. 1956			
Ridges	1009	1059	5
South slopes	1300	1289	−1
North slopes	1343	1389	3
Draw	2231	2885	29
Reed et al. 1961	+381	+564	48
			$\bar{X}$=27%, S=28, $S\bar{x}$=11*[3]
Flint Hills			
Herbel et al. 1959			
Ord. upland	1749	2080	19
Limestone break	1419	1916	28
Clay upland	1116	968	−13
Launchbaugh 1957	1245	1963	58
			$\bar{X}$=23%, S=29, $S\bar{x}$=15*[3]
Colorado Seeded Range			
Currie et al. 1970			
Agropyron cristatum	1270	1264	0
Bromus inermis	755	787	4
Agcr and Brin	1578	1479	−6
Agropyron intermedium	894	907	2
Elymus junceus	638	885	39
			$\bar{X}$=8%, S=18, $S\bar{x}$=8***
New Mexico			
Valentine 1970	77	159	106
Colorado			
Smith 1967	+85	+18	−79
Wyoming			
Pond 1961			
Granitic soil	.74	.9	22**
Sedimentary soil	1.48	2.58	74**
Utah			
Cook 1971	−11%	+17%	255*
Pacific Northwest			
Skovlin et al. 1976			
Grassland	+57	+43	−25*
Forest	−128	−108	16*
Average for Western Ranges			$\bar{X}$=28%, S=33, $S\bar{x}$=8***

*Treated as outliers, and not included in the analysis.
**Measured in grams per plant.
***Confidence interval of the mean was calculated at a 95% level.

Management Implications

Tables 1, 2, and 3 can be interpreted to predict herbage response to grazing management procedures on Western ranges. Herbage production can be expected to increase an average of 13±8% when grazing systems are implemented. Federal land management agencies could also use the 13±8% increase as a basis for associated livestock and socio-economic predictions in their environmental impact statements.

Geographically, herbage response to grazing systems was most variable in the Southwest. This variation (6±41%) makes it difficult, if not impossible to predict consistent herbage response. Therefore, it appears that livestock adjustments become increasingly important as a management tool in this region. In contrast, herbage response to grazing system implementation is less variable in Texas. Thus, it becomes a more feasible management tool in this region.

It is not possible to evaluate grazing system implementation at a light stocking intensity. Gibbens and Fisser's (1975) study on a big sagebrush range is most applicable. They felt that a lig[ht] stocking rate was the reason vegetal cover did not sho[w] differences between rest rotation, deferred, or seasonlon[g] grazing.

It is possible to compare the alternatives of implementing [a] grazing system at moderate use or of reducing livestoc[k] numbers to a light level. For example, in the Northern Gre[at] Plains, herbage response will increase by 27±21% whe[n] livestock use is reduced from moderate to light. Herbag[e] response to grazing systems averages −0.7±9%. In this sit[u]ation, livestock adjustments may be more economically feasib[le] for an individual operator (Klipple and Bement 1961). But lan[d] management agencies must consider social, economic, an[d] other factors before they decide to adjust livestock from moderate to light, implement grazing systems, or do a combination of both alternatives.

Land managers are also confronted with the situation of implementing grazing systems and simultaneously reducing livestock use from a heavy to moderate level. Tables 1, 2, and 3 can be used to evaluate the alternatives. For example, livestock adjustments result in a 35% and grazing systems a 13% increase in herbage production. These values can be adjusted proportionately to account for the total herbage response. It is assumed this would be an additive effect, resulting in the total response. Thus, livestock adjustments, from heavy to moderate use, would account for 73%, and grazing systems for 27% of the total herbage response when both are implemented simultaneously.

Conclusions

Results from a number of controlled grazing studies show that mean herbage production will increase by $13 \pm 8\%$ when grazing systems are implemented, at a moderate use level on Western ranges. This is a smaller response than is obtained when livestock use is reduced from heavy to moderate, or from moderate to light. These livestock adjustments cause herbage production to increase by $35 \pm 14\%$ and $28 \pm 13\%$, respectively. This suggests that land managers should place more emphasis on proper stocking intensity, and less on grazing system implementation.

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Fertilizing and Burning Flint Hills Bluestem

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Abstract

Burned and unburned Kansas Flint Hills range was fertilized in early May with 0, 40, and 80 lb N/acre/year and grazed from May 1 to October 1. Fertilizing with 40 lb N/acre increased carrying capacity per pound of nitrogen applied more than 80 lb N/acre did. Maintenance of good quality range was favored by burning and 0 and 40 lb N/acre compared to not burning and the same fertilizer rates. Eighty lb N/acre produced poor quality range whether burned or not. Individual steer gains were highest on burned pastures with 0 and 40 lb N/acre compared to unburned pasture at those same rates or pastures with 80 lb N/acre whether burned or not. Increased carrying capacity on fertilized pastures compared to unfertilized gave higher gains/acre.

Nitrogen is apparently the most limiting factor in herbage production of Kansas Flint Hills range (Owensby et al. 1970). Range fertilized at 50 lb/acre of nitrogen has produced twice the herbage of unfertilized plots (Mader 1956; Moser and Anderson 1964). Changes in stand composition toward cool-season grasses and weedy forbs have been the major deterrent to nitrogen fertilization of Flint Hills grasslands.

Anderson et al. (1970) indicated that cool-season grasses and weedy forbs were reduced by late spring burning. Gay and Dwyer (1965) in a one-year study on ungrazed Oklahoma True Prairie found that fire and nitrogen in combination produced 0.8 ton/acre and 1.0 ton/acre more herbage at 50 and 100 lb N/acre, respectively, than burned, unfertilized True Prairie. No fertilizer response was obtained from unburned, fertilized areas.

We studied the effects of no burning and late spring burning with 0, 40, and 80 lb N/acre on herbage production, stand composition, basai cover, and steer gains on bluestem range.

Materials and Methods

Study Area

The study area was four 60-acre and two 44-acre pastures on the Kansas State University Experimental Range Unit (Donaldson Pastures) in the northern Kansas Flint Hills near Manhattan, Kans. Big bluestem (*Andropogon gerardi* Vitman), little bluestem (*Andropogon scoparius* Michx.), and Indiangrass [*Sorghastrum nutans* (L.) Nash] were the major dominants. Kentucky bluegrass (*Poa pratensis* L.) and sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], along with numerous perennial grasses, forbs, and woody species, constituted the remainder of the plant community. Soils were transitional udic ustolls to udolls. Range sites varied from deep, well-drained sites to rocky to clayey areas. Principal range sites common to all pastures were loamy upland and breaks (Anderson and Fly 1955).

Treatments

Nitrogen was aerially applied as urea in 1972 and as ammonium nitrate in 1973, 1974, and 1975 during early May to burned and unburned pastures stocked at various rates with yearling steers (Table 1). Burning was the last week in April.

Table 1. Nitrogen and burning treatments and stocking rates on six Flint Hills bluestem pastures, 1972-1975.

	N-rate (lb/acre)	Stocking rates, steers (acres/animal unit) 1972	1973	1974	1975
Burned (late April)	0	5.0	5.0	5.0	5.0
	40	3.3	3.3	3.3	3.3
	80	2.2	2.2	2.8	2.8
Not burned	0	5.0	5.0	5.0	5.0
	40	3.3	3.3	3.3	3.3
	80	2.2	2.2	2.8	2.8

Plant Census

Basal cover and % composition were determined by the modified step-point system (Owensby 1973). Three sets of 500 points were taken in each pasture along lines forming a grid of the entire pasture. Analysis of variance was run on the change in basal cover and composition from pretreatment levels by certain species and groups of species for loamy upland and breaks range sites.

Herbage Production

Herbage remaining at growing season's end was harvested from fifteen 1/10,000th-acre plots randomly located on loamy upland and breaks range sites in each pasture. Herbage was separated into perennial grass and forb-brush components, dried, and reported as pounds of dry matter per acre. Because cages tend to distort total herbage yield estimates (Owensby 1969), steer days per acre plus the herbage remaining after grazing were used to estimate total herbage production in each pasture.

Cattle

Steers, approximately 14 months old and individually identified grazed the pastures from May 2 to October 3, 154 days. All were gathered the first of each month, penned overnight without feed or water, and weighed the next morning.

Statistical Analyses

Analyses of variance were run using subsamples to estimate the error variance since the experiment was not replicated. Though not completely valid statistically, those analyses indicate probable differences.

Results and Discussion

Herbage Yield

Perennial Grass Component

At the end of the growing season, more perennial grass remained after grazing on unburned than on burned pastures (Table 2). On unburned pastures more perennial grass remained on the breaks than on loamy upland range sites, but on burned pastures amounts remaining were the same for both range sites

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Table 2. Perennial grass (lb D.M./acre) remaining on grazed loamy upland and breaks range sites at season's end (1972-74 avg.).

	N, lb/A		
	0	40	80
Not burned			
loamy upland	2067	1567	1509
breaks	2910	2499	2382
Burned			
loamy upland	1489	1836	1069
breaks	1477	1751	1121

$LSD_{.05} = 482$

On unburned pastures less perennial grass remained on fertilized pastures than on the unfertilized; on the burned pastures 0 and 80 lb/acre of nitrogen left comparable amounts, both less than where 40 lb/acre was applied.

Forb-brush Component

Forb-brush herbage remaining at growing season's end on grazed loamy upland and breaks range sites was the same regardless of N-rate on unburned pastures, but less remained on burned pastures at the 0 and 40 lb N-rates than on unburned pastures at the same N-rates (Table 3). Forb-brush amounts remaining on the 80-lb, N-rate, burned pasture were comparable to those of the unburned pastures. The 80-lb N-rate pasture did not burn well, which likely accounted for its similarity with unburned pastures in amount of forb-brush remaining.

Table 3. Forb-brush (lb D.M./acre) remaining at season's end on grazed loamy upland and breaks range sites (1972-74 avg.).

	N, lb/A		
	0	40	80
Not burned			
loamy upland	582	533	546
breaks	462	584	485
Burned			
loamy upland	289	268	555
breaks	155	343	634

$LSD_{.05} = 225$

Steer Days Plus Remaining Herbage

Higher stocking rates on fertilized pastures produced more steer days/acre (Table 4). After the first 2 years of the study, stocking rates on the 80-lb, N rate pastures were reduced because too little herbage remained at season's end to maintain vigor of the dominants. A combination of steer days/acre and herbage production indicated that the 80-lb N-rate was not desirable since the 40 lb N/acre gave results nearly as good. Burning and 40 lb/A of nitrogen appeared to be the best for increasing stocking rate and maintaining herbage production.

Plant Census

Plant census is reported as the change in percentage composition and basal cover of the major components of loamy upland and breaks range site from pretreatment (1971) to posttreatment (1975).

Table 4. Steer days/acre on burned and not burned pastures with indicated nitrogen rates (1972-1975).

N, lb/A	1972-73	1974-75
0	45.5	45.5
40	68.2	68.2
80	107.1	83.3

Basal Cover

Big bluestem, Indiangrass, and Kentucky bluegrass exhibited greatest differences in basal cover changes among treatments (Fig. 1). Big bluestem and Indiangrass basal cover increased on burned pastures with 0 and 40 lb N/acre during the 4-year period, but decreased on the unburned pastures with the same fertilization rates. On pastures with 80 lb N/acre big bluestem and Indiangrass basal cover decreased whether burned or unburned. Apparently, burning favored those warm-season, sod-forming grasses. The 80 lb N-rate pastures were probably stocked too heavily, which likely reduced vigor of palatable, preferred species.

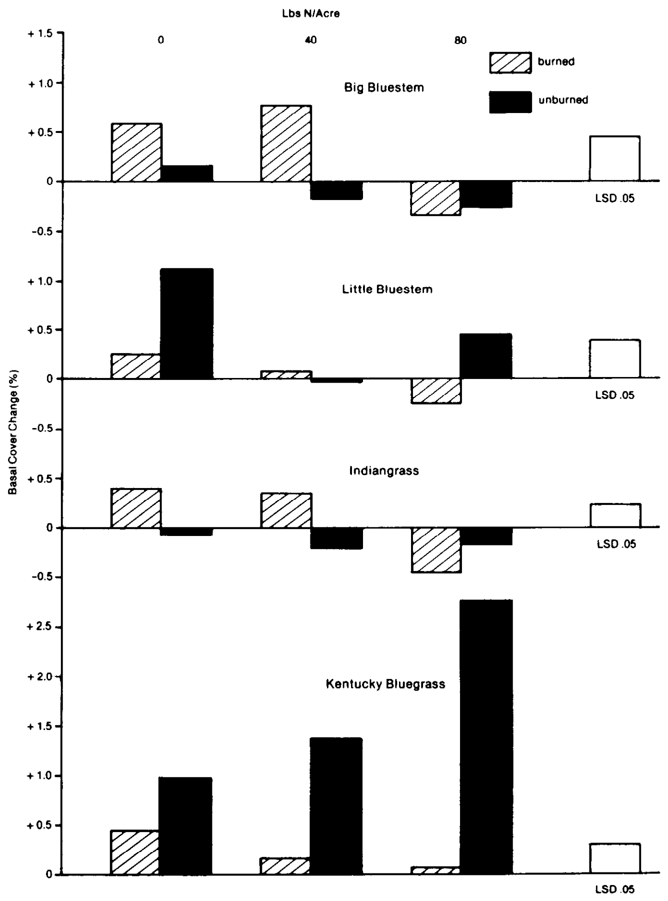

Fig. 1. *Changes in basal cover (%) of different grasses from pretreatment levels (1971) to post-treatment levels (1975) under indicated nitrogen and burning treatments (avg. of loamy upland and breaks range sites).*

Kentucky bluegrass basal cover increased as nitrogen rate increased on unburned pastures (Fig. 1). On burned pastures the basal cover changes were less and decreased as fertilizer rate increased. Greatest increases in Kentucky bluegrass basal cover came on loamy upland range sites (Table 5).

Basal cover of grass-like plants (mostly sedges) increased more as nitrogen rate increased (Table 5). Like Kentucky bluegrass, grass-like plants were mostly cool-season and began growth earlier than the warm-season perennial grass dominants and thus were favored by nitrogen application.

Composition Percentages

The major warm-season perennial grass dominants (big bluestem, Indiangrass, and little bluestem) decreased in relative amount of the total basal cover from 1971-1975 regardless of

Table 5. Changes in basal cover (%) Kentucky bluegrass and grass-like plants for indicated nitrogen treatments on loamy upland and breaks range sites (avg. of burned and unburned treatments). 1971 was pretreatment level.

	N, lb/A		
	0	40	80
Kentucky bluegrass			
loamy upland			
1971	0.16	0.22	0.11
1975	1.26	1.47	2.35
Change	+1.10	+1.25	+2.24
breaks			
1971	0.07	0.06	0.08
1975	0.37	0.33	0.64
Change	+0.30	+0.27	+0.56
LSD $_{.05}$=0.30*			
*Grass-like plants			
1971	0.22	0.18	0.22
1975	0.84	1.03	0.73
Change	+0.62	+0.85	+0.51
LSD $_{.05}$+0.20*			

*LSD applies only to the change in basal cover.

treatment (Fig. 2). Big bluestem and Indiangrass composition % were reduced more on unburned pastures than on burned for pastures with 0 and 40 lb N/acre. Pastures with 80 lb N/acre had more reduction in big bluestem basal cover and less reduction in Indiangrass basal cover on unburned than burned range. Overall burning was detrimental to composition % of little bluestem.

Kentucky bluegrass composition % increased on unburned pastures as nitrogen rate increased, but did not change on burned pastures. Loamy upland had greater increases in composition % of Kentucky bluegrass than did breaks range sites (Table 6).

Plant Census Summary

Basal cover of the desirable warm-season perennial grasses generally increased under burning and fertilizing with 0 and 40 lb N/acre more than under unburned treatments. At the 80 lb N-rate desirable warm-season species decreased in basal cover on both burned and unburned pastures, and remained relatively constant on unburned pastures at the 0 and 40 lb N-rate. Basal cover of less desirable grasses and forbs increased much more at all nitrogen rates on unburned pastures than burned. Apparently, without fire, fertilizing at the 40 lb N-rate did not maintain a high quality stand. Fertilizing with 80 lb N/acre did not maintain high quality stands whether burned or unburned.

Table 6. Changes in percent composition (% of total basal cover) of Kentucky bluegrass under indicated nitrogen treatments on loamy upland and breaks range sites (avg. of burned and unburned (treatments). 1971 was the pretreatment level.

	N, lb/A		
	0	40	80
Kentucky bluegrass			
loamy upland			
1971	4.3	5.2	2.9
1975	15.6	16.0	25.6
Change	+11.3	+10.8	+22.7
breaks			
1971	1.7	1.3	1.8
1975	4.2	6.6	9.8
Change	+2.5	+5.3	+8.0
LSD $_{.05}$=2.7*			

*LSD applies only to the change in % composition.

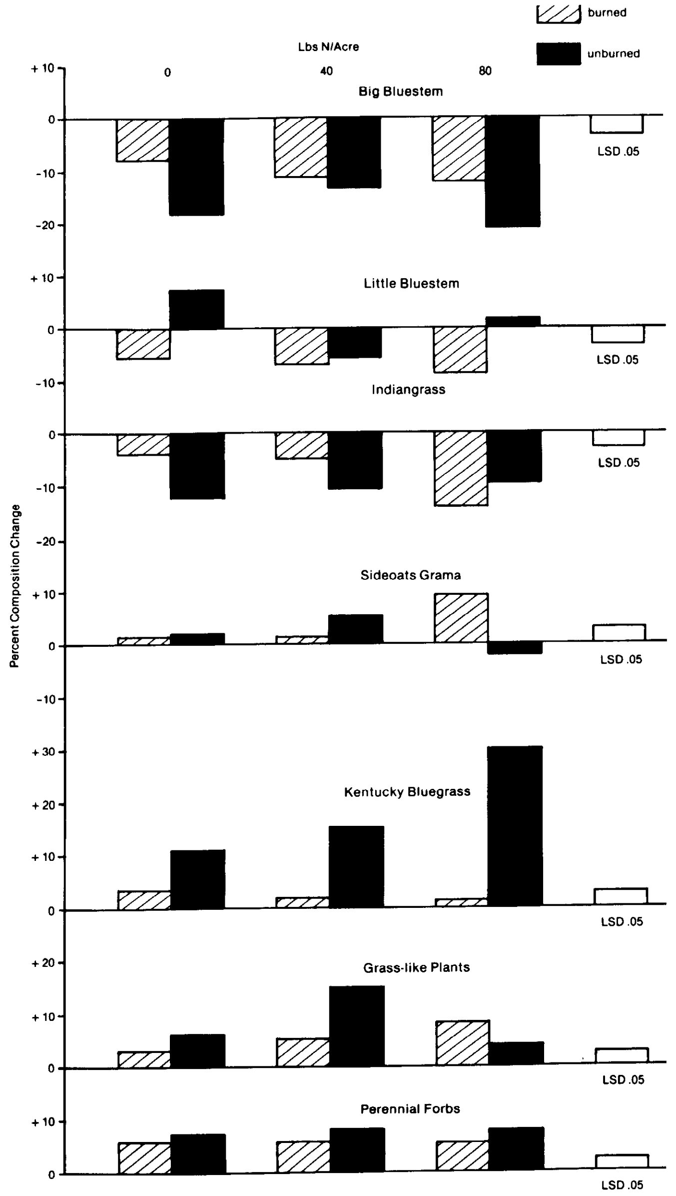

Fig. 2. *Changes in composition percentages (% of total basal cover) of different grasses from pretreatment levels (1971) to post-treatment levels (1975) under indicated nitrogen and burning treatments (avg. of loamy upland and breaks range sites).*

Composition percentages of desirable species in the stand decreased more on unburned pastures, particularly at the 80 lb N-rate, than on burned ones. On burned pastures undesirable species increased slightly in composition %, but on unburned pastures increases were large. Burning and fertilizing with 40 lb N/acre seemed to improve maintenance of good quality range. Fertilizing with 80 lb N/acre failed to maintain good quality range whether burned or not.

Previous work on grazed and ungrazed areas with late spring burning in Flint Hills bluestem range showed similar vegetative responses to those reported here. Late spring burning favored warm-season perennial grasses and reduced cool-season grasses and perennial forbs compared to not burning (Anderson et al. 1970; McMurphy and Anderson 1965; Aldous 1934). Earlier research on nitrogen fertilization of ungrazed Flint Hills bluestem range indicated that cool-season grasses and perennial forbs were favored by adding nitrogen, and warm-season perennial grasses were reduced compared to unfertilized areas (Owensby et al. 1970; Mader 1956; Moser and Anderson 1964). Results agree with the findings in this study.

Steer Performance

Gain per Steer

Individual steer gain was generally greater on burned pastures than on unburned, probably because forage quality was higher. Allen et al. (1976) reported that nitrogen free extract was increased and cell wall constituents decreased for big and little bluestem on burned pastures compared with unburned ones. Anderson et al. (1970) reported higher gain per steer on late spring burned Flint Hills bluestem range than unburned. On unfertilized pastures, gain per steer was greater on burned pastures than on unburned 2 of the 4 years and the same the other 2 years (Table 7).

Table 7. Average steer gains (lb/steer) from late spring-burned and unburned bluestem pasture fertilized as indicated.

		Pounds of gain/steer, May 2-Oct. 3, 154 days		
		Nitrogen, lb/A		
Year	Treatment	0	40	80
1972	Burned	183^{ghi}	217^{ij}	195^{h}
	Unburned	135^{cde}	152^{ef}	116^{b}
1973	Burned	160^{fg}	154^{ef}	128^{bcd}
	Unburned	137^{cdef}	120^{bc}	101^{a}
1974	Burned	261^{k}	230^{j}	185^{h}
	Unburned	197^{hi}	154^{ef}	154^{ef}
1975	Burned	181^{gh}	178^{gh}	146^{def}
	Unburned	179^{gh}	147^{def}	137^{cdef}

[a] ab . . k Means with different superscripts differ significantly ($P \leq .05$).

On pastures fertilized with 40 lb N/acre gain per steer was higher on burned pastures than unburned each year. Individual steer gain on the unfertilized, burned pastures was lower in 1972, greater in 1974, and similar in 1973 and 1975 to gains on pastures fertilized with 40 lb N/acre. Individual steer gain was greater in the unburned, unfertilized pasture than on unburned pastures with 40 lb N/acre in 1974 and 1975 and similar in 1972 and 1973.

Steers gained less on the unburned pasture with 80 lb N/acre than on burned ones fertilized at the same rate every year except 1975. Three of the four years, steers gained less on burned pastures with 80 lb N/acre than they did on pastures with 0 and 40 lb N/acre. In 1972, individual steer gain was similar for burned pastures with 0 and 80 lb N/acre, and less than that on the burned pastures with 40 lb N/acre. During the first 2 years of the study, steers on the unburned pasture with 80 lb N/acre gained less individually than those on pastures with 0 and 40 lb N/acre. The last 2 years, the unburned pasture with 80 lb N/acre had gain per steer similar to that on the unburned pasture wth 40 lb N/acre; both were less than gain per steer on the unburned pasture without nitrogen.

Apparently, failure of steers to gain as well on pastures with 80 lb N/acre was due partly to overstocking and reduced forage selectivity by steers. Table 2 shows less forage remained on pastures with 80 lb N/acre at the end of the growing season than on other pastures.

Gain per Acre

Gain per acre on fertilized, unburned pastures was not significantly greater than on the unburned, unfertilized one. Since pastures receiving additional nitrogen were stocked at a higher rate (Table 1) to use additional forage, more gain per acre would be expected unless individual steer gain was greatly reduced. That happened on the unburned pasture with 80 lb N/acre, where in each of the 4 years individual animal gains were reduced. In 2 of the 4 years, gain per steer was lower on the unburned pasture with 40 lb N/acre than on the unburned, unfertilized pasture (Fig. 3). Allen et al. (1976) reported big and little bluestem were similar in most nutritive components whether on an unburned pasture with 40 lb N/acre or on an unburned, unfertilized pasture. Possibly, changes in botanical composition in the fertilized, unburned pastures compared to changes on the unburned, unfertilized one were responsible for the reduced animal performance.

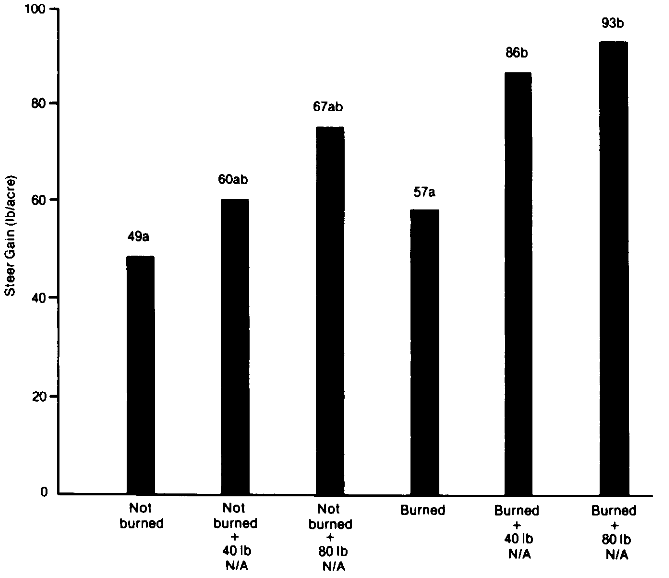

Fig. 3. *Gain per acre by steers on bluestem pasture, May 1 to Oct. 3, 1972-75. Numbers with different letters differ significantly (P>.05). Numbers are pounds gain per acre.*

On burned pastures, gain per acre was greater on fertilized than on the unfertilized one. Pastures with 40 and 80 lb N/acre had similar gain per acre even though stocking rate was greater on the 80 lb N-rate pasture than the 40 lb N-rate one. Again, the reduced gain per head on pastures with 80 lb N/acre was responsible for the similarity in gain per acre between pastures with 40 and 80 lb N/acre.

Conclusions

1. Fertilizing with 40 lb N/acre increased carrying capacity per pound of nitrogen applied more than did fertilizing with 80 lb N/acre, both compared with no fertilization.
2. Maintenance of good quality range was favored by burning and 0 and 40 lb N/acre compared with not burning and the same fertilizer rates. Eighty lb N/acre produced poor quality range whether burned or not.
3. Kentucky bluegrass and perennial forbs increased more on unburned pastures than on burned, with the greatest increases under nitrogen fertilization.
4. Individual steer gains were highest on burned pastures with 0 and 40 lb N/acre compared to unburned pastures at those same rates or pastures with 80 lb N/acre whether burned or not.
5. Forty lb N/acre applied to late spring-burned bluestem pasture seems to represent the best combination of the treatments tested.

6. Even though stocking rate and nitrogen fertilization rates are confounded, making it difficult to determine cause and effect relationships, the research does indicate which of the treatments applied gave the most favorable results.

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Vegetation Stagnation in Three-Phase Big Game Exclosures

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Abstract

The allocation of range forage for deer and livestock is an important range management problem. Utilization of the three-phase exclosure technique for such evaluations is complicated by the response of plants to nonuse. Protection from browsing can cause "stagnation" to occur as early as the second year after the exclosure is established. Nonuse of bitterbush resulted in an average reduction in production of 70%. Temporary exclosures moved each year are required for accurately determining annual forage production.

Resource managers lack methods that will give reliable estimates of site productivity and its relationship to carrying capacity for either livestock or big game. One procedure often followed for partitioning forage has been the use of three-phase exclosures.

This paper reports a 6 year study to determine site productivity (i.e., pounds of vegetation produced per hectare) through the use of three-phase exclosures and temporarily erected movable exclosures. Production refers to the total annual dry matter increment of grasses, forbs, and browse. Effects of different species, plant density and dispersion characteristics, vegetation stagnation caused by lack of grazing, and site differences within three-phase exclosure all tend to confound range production and utilization data. Factors considered to influence these results are precipitation, past utilization, condition and trend of the vegetation, and the period of protection from grazing. *Stagnation* can be defined as the reduction in productivity of range plants resulting from a lack of grazing.

Use of exclosures for rangeland evaluation has received wide acceptance. Daubenmire (1940) defined the exclosure as any experimental area which is protected from the activities of a particular class of animal by a barrier such as a fence or screen. They have some drawbacks, such as the barrier effect which will influence wind movement, precipitation, and seed collection. Three-phase exclosures were used as early as 1932, to discover and demonstrate the food preferences of animals (Young 1955). Each phase should be 1 acre (.405 hectare) or larger to have the least effect on the probability that deer will enter and should be located so that all phases are located on a single vegetatively homogeneous and representative part of the rangeland (Young 1958). Jones (1965) and McMahon (1966) have used the exclosure technique to study relative utilization, cover and compositional changes, and other effects.

Methods

Four important Nevada deer ranges and corresponding exclosure sites were selected for this study. Paine Springs, White Rock, Morey Bench, and the Fort Ruby sites were selected on the basis of vegetal homogeneity among exclosure phases and because they represent important deer winter range habitat-types.

The Paine Springs exclosure, built in 1962, is located in the Duck Creek Basin, near McGill in White Pine County within an *Artemisia tridentata/Purshia tridentata/Poa secunda* plant community at 2,073-m elevation. The White Rock exclosure, near White Rock Peak in Lincoln County, is situated in an *Artemisia tridentata/Purshia tridentata/Poa secunda* plant community at approximately 2,190-m elevation and was constructed in 1965. Morey Bench is in Hot Creek Valley east of Tonopah in Nye County. A three-phase exclosure was built there in 1965 situated in an *Artemisia tridentata/Purshia glandulosa/Prunus andersonii* plant community at the base of Morey

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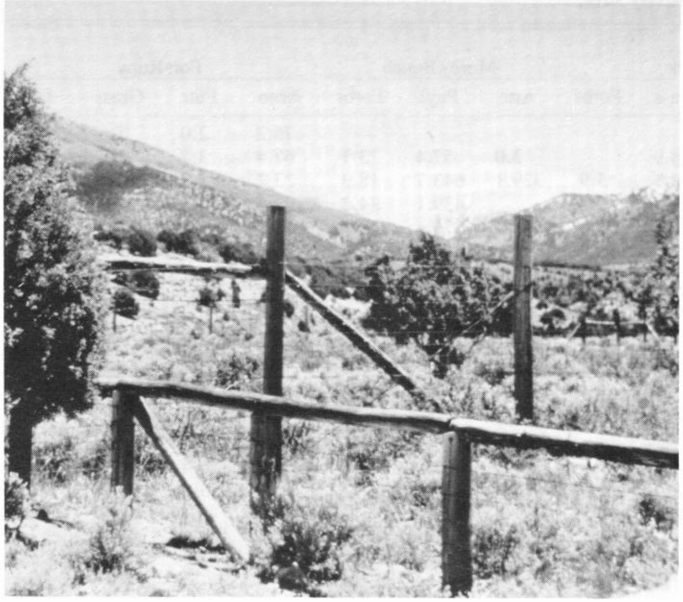

Fig. 1. *The Three-Phase Exclosure: Phase A (high fence) and Phase B (low fence).*

Peak (2,072 m). The Fort Ruby exclosure, constructed in 1959, is located at 1,920 m elevation just south of the Ruby Marshes in White Pine County. The boundaries of the latter exclosure encompass an ecotone comprised of the *Pinus monophylla/Juniperus osteosperma/Artemisia nova* and the *Artemisia nova/Chrysothamnus viscidiflorus/Purshia tridentata* plant communities.

All exclosure areas consist of three phases (Fig. 1), each encompassing .405 hectares (1 acre): one phase is fenced to exclude all foraging (Phase A); a second fence excludes livestock but allows deer foraging (Phase B); the third is unfenced and allows both livestock and deer foraging (Phase C). The following assumptions are made: highest production, a measure of site potential, is achieved in Phase A; deer utilization is represented by the difference in production between Phase A and Phase B following the foraging season; livestock utilization is derived from Phase B production after grazing less Phase C production after grazing.

Vegetation at each site was originally described using a modification of the method described by Poulton and Tisdale (1961) including cover and density. Ten transects each of ten contiguous frequency quadrats were employed to determine frequency. Twenty- or 30-inch (50.8 or 76.2 cm) square quadrats were used. During the summer of 1969, cover data were obtained from individual clip plots of both temporary and permanent exclosures. Height in meters to the highest point and density measurements of selected shrub species were taken within the 20 ft by 20 ft (6.1 × 6.1 m) clip plots.

Annual Forage Production

Production data were obtained by the clip before-and-after method. Bitterbrush was clipped on plots 20 ft by 20 ft (6.1 × 6.1 m). Sagebrush and other shrub species were clipped from a 10 ft by 10 ft (3.05 × 3.05 m) plot, and production of grasses and forbs was determined by clipping a plot 4 ft by 12 ft. Both latter plots were nested within the larger plot. Five 20 ft by 20 ft (6.1 × 6.1 m) clip plots were located at random from among the total of 100 in each phase. By restricting the randomization, new plots were clipped each year.

Grasses and forbs were clipped at ground level. Bitterbrush and serviceberry were clipped of all current year's twig growth. On sagebrush current annual growth is difficult to determine. Therefore, new shoot length was estimated before being clipped. Data represent total annual vegetative yield and not necessarily available forage. However, it is felt that all material clipped in this study was available to the grazing animal. Clippings were oven dried at 70° for 48 hr., weighed, and the weights converted to kilograms/hectare.

Five temporary exclosures square in shape, each encompassing an area of 400 ft^2 (37.16 m^2), were located within Phase C at each exclosure site during the summer of 1968. Five older temporary exclosures of the same dimensions were erected at the Paine Springs and Morey Bench sites in the summer of 1966.

The temporary exclosures were used to supply a better estimate of site potential than that obtained from Phase A, or the continuously protected area. They provide protection from grazing for one growing season only, and were moved each year. Total annual production was measured on the vegetation within these structures and compared to that taken from Phase A. By this comparison the effect of stagnation can be quantified.

Employment of the temporary exclosure technique makes possible the assessment of the effects of stimulation provided by grazing on forage production. This technique eliminates the influence due to "stagnation" and gives a better estimate of the annual potential production of a particular site.

Shrub yields were corrected on the basis of volume-of-area occupied per species in an effort to overcome the problems of vegetation heterogeneity among phases. Harniss and Murray (1976) have shown that the dry leaf weight production of sagebrush can be estimated from height and circumference measurements. Their literature review showed that shrub production can be related to crown diameter, stem diameter, foliage cover and basal area and known volume. Similar relationships held true for certain grasses (Pasto et al. 1957; Evans and Jones 1958; Frakes 1959; Reppert 1962; Payne 1974; Uresk et al. 1977).

A multiple linear correlation analysis was used to test the relation of cover, height and density to yield. The relation of each sampled parameter to yield was determined for sagebrush and bitterbrush taken from each sample plot. If the correlations were found to be significant, the standard partial regression coefficients were computed and used as measures of the relative importance of each independent variable on yield. In this manner, a weighted index using the standard partial regression coefficients of each independent variable can be used to correct the yield data of each phase of the exclosure to that recorded from the temporaries. This constitutes a correction to a level of production that could be expected if stagnation had not been a factor.

The formula derived to correct yields of the various exclosure phases to that taken from the temporaries is:

Estimation of Deer Use

Relative deer use among the exclosure phases was tested (a *t*-test for paired plots) by comparing counts taken from each phase of the exclosure system. Pellet groups were counted in ten 0.01-acre (0.004 ha) plots in each phase. These values were divided by 13, the average pellet groups/day/deer, in order to convert the data to deer-days use per acre (Smith 1964). Counts were not significantly different at the 0.05 level of probability, and deer use between Phase C and Phase B was considered equal.

Results

The protected areas must produce the same quantity as the browsed and grazed vegetation if the three-phase exclosure is to provide information on deer-livestock competition as computed from differences in utilization. Data from our four study sites show that the effect of vegetation stagnation precludes this capability.

Paine Springs

Production data (Table 1) were too variable for any conclusions concerning deer-livestock competition or for comparisons of the vegetation production among exclosure phases. However, the erection of temporary exclosures provided data on total vegetation production. Cover, height and density were significantly related to the corresponding yield of bitterbrush in simple and multiple linear regression analysis (Table 2). The standard partial regression coefficients have been weighted

Table 1. Yields expressed in kilograms/hectare of oven-dry forage at four study sites.

Study site		Paine Springs				White Rock				Morey Bench			Fort Ruby			
Phase	Year	Artr	Putr	Grass	Forbs	Artr	Putr	Grass	Forbs	Artr	Pugl	Forbs	Arno	Putr	Grass	Forbs
A	1964	101.5	54.0	74.0									75.2	2.0	3.6	
	1965	112.3	37.8	91.5		239.2	69.6	48.9		3.0	57.4	23.1	67.4	3.7	7.2	
	1966	46.7	1.2	140.8	11.2	79.5	63.9	52.5	5.9	329.1	643.7	18.3	23.2	2.9	10.3	5.8
	1967	402.3	56.1	129.2	11.5	371.1	52.5	37.7	50.2		439.1	34.2	102.4	5.1	26.9	57.4
	1968	78.1	11.1	191.4	7.9	73.2	10.1	216.4			176.4		39.0	2.4	33.4	23.6
	1969	157.4	16.1	167.2	22.6	436.2	52.5	79.5	14.9		8.2		96.3		91.5	100.3
B	1964	85.9	38.4	79.4									48.2	1.7	5.8	
	1965	41.4	66.1	139.9		223.6	36.9	40.9		8.4	33.7		58.6	0.7	13.4	
	1966	65.4	5.7	45.4	2.6	299.8	33.5	41.4	14.5	32.7	569.6	10.8	101.2	3.9	7.1	
	1967	63.9	53.9	123.3	16.7	324.1	106.5	52.2	19.7		611.5		94.9	14.9	31.9	88.9
	1968	136.7	30.1	174.3	0.6	231.2	18.3	27.2			204.2		73.9	1.1	23.8	1.6
	1969	173.8	8.7	117.4	2.4	478.3	114.3	73.2			29.9		191.4	6.0	36.8	
C	1964	97.6	11.2	36.7									52.1	0.3	0.9	
	1965	110.3	17.3	36.4		157.3	22.2	44.4		8.0	13.4		24.7	0.4	6.3	
	1966	32.3	4.5	19.7	3.0	115.7	19.2	18.9	10.0	15.7	394.5		46.7	3.8	2.6	2.6
	1967	137.6	90.8	102.6	30.5	234.4	121.3	42.5	18.9		592.7		193.6	3.6	28.7	4.9
	1968	84.2	28.6	53.9	1.6	222.4	10.8	25.0			135.6		99.4	1.9	0.6	
	1969	140.2	18.9	62.7	5.9	396.1	83.9	33.6			21.0					
Old temporaries	1967	284.1	105.7	98.6	13.8						426.3	89.7				
	1968	81.1	84.5	244.9	55.3						26.2					
	1969	208.6	102.9	181.7	11.2						31.4					
New temporaries	1969	277.8	40.8	110.7	17.9	450.9	181.4	88.1	1.0		97.4		432.1	6.9	49.2	20.7

Artr - *Artemisia tridentata*
Arno - *Artemisia nova*
Putr - *Purshia tridentata*
Pugl - *Purshia glandulosa*

44.1% for cover, 26.1% for height, and 29.8% for density.

For the 1969-1970 period, potential production of bitterbush in the temporary exclosures was 40.8kg/ha while yield from the completely protected area was only 16.1 kg/ha. Hence, Phase A produced only 39% of its potential in 1969, and stagnation has accounted for a 61% reduction in production following protection for 8 years. A correction of yield in the A phase based on the weighted index shows that without the effect of stagnation the production of bitterbrush based on cover, density, and average height of plants should have been 41.56 kg/ha.

Cover percentages of *Artemisia tridentata* from the temporary exclosures and Phase A were 10.43% and 10.94%, respectively (Table 3). However, sagebrush in Phase A has produced only 59% of that recorded from the temporaries. For rabbitbrush (*Chrysothamnus viscidiflorus*), the temporaries produced approximately one-third of that recorded in Phase A. For grasses, the results were variable. The old temporaries had higher yields in 1968 and 1969 but not in 1967. This is explained in part by the effect protection from grazing has on plants previously subjected to heavy utilization. Although basal cover estimates for grasses were approximately equal, yield was greater in plots protected for 8 years. Perhaps the stagnating effect expressed by shrubby species allows for a "release" of previously suppressed grass species so that growth and subsequent yield are increased. Data from the control plots (Phase C) indicate that stagnation has, indeed, occurred for shrubs. Shrub species show a large reduction in productivity as a result of continued protection from grazing. Whenever the B or C phase outproduces the A phase, some irregularity in the technique is indicated. On the other hand, grasses and forbs show a definite increase in total forage produced due to protection from grazing, even though production outside is greater during a good year. These data suggest that the area is not presently being grazed at its potential. Yield figures from two different sets of temporary exclosures show potential forage production from all plants to be greater than 448 kg/ha of oven dry forage.

Comparisons of the data obtained from the temporary and existing exclosures indicate that protection from grazing has caused a sizable reduction in the amount of browse production. Both bitterbrush and sagebrush were at a static low level of production due to the lack of utilization. Results from the old temporary exclosures show that 100% simulated utilization for those two species over 3 years, a measure of site productivity, produced yields that were greater than from those plants receiving "normal" grazing at the Paine Springs site. This suggests that the "normal" grazing patterns were not sufficient to provide the annual grazing stimulus required to give optimum browse production at some judicious utilization rate.

White Rock

Initial results appeared favorable for the prediction of the relative use by wildlife and livestock for bitterbrush and sagebrush (Table 1). However, the effects of stagnation were obvious after less than 2 years.

The standard partial regression coefficients calculated from the analysis of cover, height and density (Table 2) were rated 39.94%, 19.76%, and 42.30%, respectively. Phase A could have produced 172.6 kg/ha of bitterbrush under similar treatment and is comparable to the site potential obtained from the temporaries, where 181.4 kg/ha of bitterbrush was recorded. Stagnation is thought to be responsible for the phase A production of only 52.5 kg/ha of bitterbrush, or 30% of its potential. Stagnation has accounted for a 70% reduction in production from site potential after 5 years of continued protection from the annual stimulus of grazing.

Stagnation caused less reduction in sagebrush production. Cover percentages for sagebrush show that the A phase and the

Table 2. **Simple and multiple linear correlations of vegetative parameters from bitterbrush at four study sites.**

Variables				Paine Springs		White Rock		Morey Bench		Fort Ruby	
X_1	X_2	X_3	Y	r	r^2	r	r^2	r	r^2	r	r^2
C			Yield	.919^b	.845	.816^b	.666	.878^b	.771	.841^b	.707
H			Yield	−.778	.605	.467	.218	−.246	.058	.196	.038
D			Yield	.890^b	.792	−.802^b	.643	.654	.428	−.070	.005
C	H		Yield	.974^a	.949	.816^b	.666	.878^b	.772	.869^b	.755
C	D		Yield	.930^b	.865	.878^a	.771	.963^a	.928	.977^a	.954
H	D		Yield	.898^b	.806	.813^b	.661	.665	.442	.206	.042
C	H	D	Yield	.997^a	.994	.901^a	.812	.991^a	.982	.988^a	.977

C = cover; H = height; D = density; ^{a} = significant at .01; ^{b} = significant at 0.1; r — regression coefficient; r^2 = coefficient of determination

temporaries are almost equal. Yields from 1969 show production in Phase A to be slightly less (436 kg/ha) than that taken from the temporary exclosures (451 kg/ha) (Table 1). Likewise, differences between the temporaries and B and C phases of the exclosure show no statistical significance.

Grass in the A Phase had a greater cover percentage but a lower density than that recorded from the temporary exclosures. Yields for the 1969 season showed production to be approximately equal and only slightly higher in the temporary exclosures when compared to the A and B phases. Yield was much lower for the C phase, indicating that production was greater in the temporaries possibly due to vigor brought about by the first years of protection from grazing. Protection from grazing for one growth season and favorable growing condition appear to be responsible for the increase in production of the grasses previously subjected to heavy annual utilization by cattle at this site. Our test was not sensitive enough to predict the effect, if any, stagnation may have had on the grass inside the completely protected area.

The differences in forb yields appear to be simply a function of frequency of occurrence and cover precentages in each phase. Forb cover in the temporaries is barely more than a trace and frequency of occurrence is less than half that in the A phase (Table 3).

Protecting the vegetation for only one growing season accompanied by favorable precipitation showed that potential forage production at the White Rock exclosure can be much greater than the level of the production represented by the control area. The temporary exclosures produced approximately 721 kg/ha of oven-dry vegetation during an average precipitation year (1969) and thus probably is a good representation of site potential.

Morey Bench

The Morey Bench exclosure was constructed in January of 1965 and the first year's production and utilization data yielded a computed 77% utilization of desert bitterbrush (Table 1). However, by 1967 stagnation was noticeable. Cover and height alone may not adequately weight the index for correcting the production yields (Table 3) at this site. The added influence of density in the computation of the correlation coefficients showed a higher level of significance than that recorded for cover times height on yield. Therefore, density measurements from within the A phase the the temporary exclosures were used

Table 3. Vegetation parameters for sagebrush and bitterbrush on four Nevada deer range in 1969.

Study Site		Paine Springs		White Rock		Morey Bench		Fort Ruby	
Parameter	Phase	Artr	Putr	Artr	Putr	Artr	Pugl	Arno	Putr
Cover (percent)	A	10.94	10.87	15.45	10.31	6.57	16.20	11.04	
	B	12.09	5.14	21.11	9.40	3.98	17.95	17.61	0.91
	C	10.46	10.24	14.19	9.49	4.51	14.01	16.02	0.29
	Temporaries	10.43	9.94	15.30	7.88	5.37	25.34	16.62	0.62
Frequency (percent)	A	75	20	86	36	27	35	71	3
	B	61	18	76	29	23	34	74	14
	C	73	15	69	50	6	27	73	4
Height (meters)	A		0.75		0.54		1.15		0.26
	B		0.72		0.56		1.13		
	C		0.67		0.32		1.07		
	Temporaries		0.64		0.43		1.19		0.39
Density	A		1453		3499		1507		1550
	B		1238		3121		1292		
	C		1507		6944		1184		
(plants/hectare)	Temporaries		1829		6027		2422		10979

Artr - *Artemisia tridentata*
Putu - *Purshia tridentata*
Arno - *Artemisia nova*
Pugl - *Purshia glandulosa*

in the computation of the index (Table 3). The standard partial regression coefficients have been weighted 48.59% for cover, 17.9% for height, and 34.22% for density.

Production in Phase A for 1969 showed bitterbrush had produced only 22% of that recorded from the temporary exclosures (8.2 kg/ha). The site could have potentially produced 37.8 kg/ha. Stagnation apparently accounted for a 78% reduction in production of the site potential in bitterbrush due to 5 years of protection from grazing. The sparse distribution of herbaceous species and the high variability of occurrence of the other shrub species among exclosure phases made analysis difficult.

An increase in precipitation during 1966 above that received in 1965 (a low precipitation year) brought a corresponding increase in yields. An even greater increase in precipitation during 1967 showed a proportionate increase in bitterbrush yields from the B and C phases. In contrast, Phase A not only produced less bitterbrush in 1967 than in the drier year of 1966, but was also outproduced by both the B and C phases during 1967, suggesting that stagnation had occurred after 2 years of protection. The potential of this site is greater than any other site studied (Table 1). The site may produce as much as 426.3 kg of bitterbrush per hectare in a good year. Forage plants protected for annual utilization by wildlife and livestock exhibited stagnation, accounting for a sizable reduction in yield. Plants hand clipped 3 successive years to simulate 100% utilization of the annual growth produced over four times as much plant material as the plants protected from grazing for 5 years and then clipped to simulate the same 100% utilization.

Results suggest (Table 1) that present utilization of the area by livestock and deer is reducing bitterbrush production. Past and present use has reduced both the average height and number of individuals per hectare in the control area (Table 3).

Fort Ruby

Bitterbrush plants were few in numbers at this location (Table 3). Black sagebrush was the dominant shrub. Forage potential for grass species was generally low due to the high proportion of low volume producers such as *Poa sandbergii*.

The standard partial regression coefficients have been weighted 55.88% for the cover, 9.96% for the height, and 34.16% for the density of *Artemisia nova* based on the regression results (Table 2). Ten years of protection from the stimulus of grazing has accounted for a 65% reduction in site productivity in terms of black sagebrush production (Table 1). Results from the previous sites show that stagnation may have occurred within 2 to 3 years after protection.

Phase A produced 96.3 kg/ha of black sagebrush during the 1969 growing season but could have produced 270 kg/ha of black sagebrush under similar treatment. Black sagebrush produced only 35% of its potential.

For rabbitbrush (*Chrysothamnus viscidiflorus*) the relative cover percentages of Phase A and the temporaries were 2.66% and 3.43%, respectively. A comparison of yields shows 92 kg/ha of rabbitbrush from the temporaries and 30.1 kg/ha from Phase A. It is doubtful that a 1% greater canopy cover of rabbitbrush can account for almost a three-fold increase in yield. It appears that stagnation has occurred in this species, also. Observations during the collection of spring clippings confirmed deer utilization of rabbitbrush.

The response of grasses and forbs to continued protection from grazing was similar to that observed on other sites. Grass and forb cover in Phase A was only slightly higher than in the temporaries. Yet grass production in the completely protected area was approximately twice that recorded from the temporary exclosures in 1969. Forb yield is almost 100.9 kg/ha in phase A as compared to 20.2 kg/ha recorded from the temporaries.

The effect of continued heavy utilization on grass and forbs becomes apparent when yields from the temporary exclosures are compared to past yields recorded from the B and C phases subject to utilization by wildlife and livestock (Table 1). Protection for 1 growth season allowed a marked increase in vegetation production. The higher production of grasses and forbs in Phase A for 1969 is not explained by the data but may be due to the higher cover of forbs and slightly higher cover of grass (Table 3). Precipitation recorded at the exclosure site since 1965 shows that favorable growing conditions prevailed during the 1969 growing season. Results from the erection of temporary exclosures at this site provide evidence that continued protection from the stimulus of grazing has a strong influence on the shrubs. The data are not clear cut for the grass and forbs components and may be partially masked by the favorable growing conditions in 1969. Additional years would be required to determine whether stagnation occurs in grass and forb species.

Discussion

Utilization of the three-phase exclosure technique for rangeland evaluation is complicated by the responses of plants to nonuse. Garrison (1953) found shrubs unclipped and/or lightly clipped generally produced the least forage. Bitterbrush plants protected for 9 years produced 71% less than those that were browsed annually (Martinson 1960). Browsing tends to remove the apical bud resulting in an increase in twig numbers due to lateral branching. The initial imbalance in the shoot-root ratio due to severe removal of top growth creates an abundance of soil moisture and nutrients which favour new shoot growth (Ferguson and Basile 1966). Twig growth on spring-pruned mountain mahogany increased from less than ½ inch annual growth before pruning to an average of 2.8 inches annual growth after pruning (Thompson 1970). Others have shown similar relationships with shrubs (Lyon 1966; Gibbens and Schultz 1962; Ferguson 1968). The utilization of course must be judicious. For example, removal of greater than 50% of the desert shrubs in late spring and summer for 3 years reduced yields, while 90% removal of current growth killed many of them (Cook 1971). However, browse production increased in many species including bitterbush, when 25 or 50% of the current year's growth was removed in fall or winter (Lay 1965).

This study has shown that nonuse in the fully protected area (Phase A) of an exclosure system causes vegetation stagnation of shrubs to occur as early as the second year after the exclosure is established. This condition was maintained for at least 8 years and, presumably, lasts indefinitely. Potential browse production in the A phase was reduced, depending on the site, from 3 to 78% of the average annual productivity of shrubs receiving the annual stimulus of browsing. Nonuse of bitterbrush resulted in an average reduction in productivity of 70%. For big sagebrush the figure was 36%.

Exclosure sites previously subjected to heavy utilization of grasses and forbs by livestock show that continued protection favors good growth and high yields of these species. Grass plants protected from grazing for several years produced up to 100% more vegetation than plants protected for only one growing season. The proper season and degree of use may be beneficial to be grazed grasses by increasing tillering, number of leaves and percent ground cover (Jameson 1963; Laude et al. 1968; Heady 1975, p. 19). In this study forb production was 20% higher in the fully protected areas than in the temporary exclosures. Stagnation exhibited by the shrub species probably contributed to the increased grass and forb yields by providing a release of moisture and nutrients to the forbs and grass. This is substantiated by the fact that basal area of grasses and forbs was the same in fully protected and the temporary exclosures. It must also be considered that grasses and forbs within the exclosures may be competing with the shrubs, thus contributing to the stagnation.

However, on some sites there is evidence to suggest that grass production, while higher in those areas protected for several years, is still lower than it might be with the annual stimulus of grazing. There is limited evidence that saliva from grazing animals adds thiamine to grasses and stimulates these plants to greater growth (Reardon et al. 1972). Grass plants inside phase A were usually large with numerous culms, many of which were dead, giving them a much different appearance than the grazed plants. It appears that the plants were unthrifty due to the many dead culms.

The effect of stagnation in exclosures can be quite vivid. This is a noteworthy value of constructing such exclosures. Much useful information can be derived from exclosures by the agencies involved with range management if they are interpreted correctly. The stagnation effects on vegetation caused by lack of grazing are often not considered when exclosures are used for demonstration.

Some level of stagnation probably exists on any site that is not receiving at least a moderate degree of annual grazing or browsing. Data from this study indicate that stagnation is also evident in the portion of the exclosure systems utilized by deer only. Yield recorded under this condition would account for the fact that the control, or C phase of the exclosure site, produces more than the B phases. This masking effect on yield serves as a great source of error in computing the relative utilization of forage by wildlife and livestock.

The three-phase exclosure technique can only be sensitive and supply reliable data in areas receiving moderate to heavy utilization (35-65%) and only when used in conjunction with temporary movable exclosures so that reliable information on annual forage production can be obtained.

Large, profound year-to-year differences in production can be attributed to weather variation. Differences in forage productivity of up to 12 times from one year to the next have been measured (Tueller and Monroe 1975). These variations may supercede or mask the effects of stagnation, or at least make it extremely difficult to measure.

The corrections used in this study to adjust yield data from clipped plots have application in providing a more accurate method of measuring the degree of relative forge utilization from within the B and C phases of the three-phase exclosure system. Smith and Urness (1962) have pointed out that relative utilization figures alone, without some index of production, cannot indicate the pounds of forage utilized by either game or livestock. However, they do reflect the pressure exerted on the range. Production data obtained in this study in conjunction with information on food preferences provided by the exclosure system justify the use of such tools in rangeland evaluation. Such exclosures may also serve as excellent training grounds for students.

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Grazing and Overstory Effects on Rotationally Burned Slash Pine Plantation Ranges

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Abstract

Light, moderate, or heavy grazing did not affect total herbage production in rotationally burned slash pine plantations approaching the first pulpwood thinning. However, carpetgrass tended to replace pinehill bluestem in the composition in proportion to grazing intensity. Grazing since tree regeneration has not affected tree crown cover, but heavy grazing reduced tree basal area. Increased tree dominance decreased herbage production, as predicted by earlier studies.

Much southern forest range is subjected to concentrated use. The same tract of land is often intensively managed for timber, grazed yearlong, and hunted heavily, year after year. Such management practices as livestock grazing, timber establishment and growth, and prescribed burning often cause major changes in the plant community. Knowing what plant changes to expect will aid planning for effective resource use.

Seasonal grazing effects on southern bluestem (*Andropogon* spp.) ranges have been reported (Duvall 1962; Duvall and Linnartz 1967), as have yearlong grazing effects on slash pine (*Pinus elliottii*) plantations 8-10 years old (Pearson and Whitaker 1974b). Several aspects of herbaceous understory-tree overstory relationships have also been studied, including herbage quality (Wolters 1973), prescribed burning (Grelen 1976), and plantation age (Pearson and Whitaker 1974a).

This paper reports some effects of grazing and tree overstory development in 13- to 16-year old rotationally burned slash pine plantations before their first pulpwood thinning.

Study Methods

The study was conducted on three range units of the Longleaf Tract, Palustris Experimental Forest, in central Louisiana. These range units had originally supported longleaf pine (*Pinus palustris*), but during early logging days they had been clearcut and converted to an open grassland. After more than 30 years in a grassland condition, the range units were regenerated to slash pine at the rate of 25% of each unit per year (1961-1964). Approximately 2,000 trees per hectare were intially established (Pearson et al. 1971).

Understory vegetation on the study area was typical for longleaf-slash pine-bluestem ranges (Grelen 1978), *Andropogon* being the most prominent genus. Rainfall averages 147 cm annually. Soils vary from poorly drained silt loams on level topography to well-drained sandy loams with slopes up to 10%.

Cattle grazed each of the three range units yearlong at a moderate intensity until 1960. Thereafter the individual units were grazed at different intensities designated as light (approximately 30% of the herbage removed), moderate (approximately 45%), and heavy (approximately 60%). The breeding herds were supplemented annually from 1960 through 1972 with about 180 kg/head of cottonseed cake (41% protein) fed from November through May; 120 kg/head of grass hay fed during late winter or on cold, icy days; and free choice minerals (Pearson and Whitaker 1972). In 1973 self-fed liquid supplements available yearlong replaced the cottonseed cake as a protein source (Grelen and Pearson 1977). Rotational grazing was encouraged by prescribe burning a different portion of each unit each winter. Successive quarters of each unit were burned during the 4 years of pine regeneration. After the fifth year successive thirds were burned.

Annually from 1961-1964 five pairs of 0.04-hectare plots were randomly located within the most recently regenerated portion of each range unit. Each pair consisted of one plot left open to grazing and one which was fenced. A distance of one chain separated grazed plots from fenced plots to avoid the effects of concentrating cattle along the fence. No cattle grazed the fenced plots for the 13 to 16 growing seasons since the plots were established, thus ungrazed control plots were present within each range unit for a reference as to grazing and site effects.

This study included the oldest (1961) and the youngest (1964) regeneration areas and totaled 10 plot-pairs in each of three range units.

Twelve temporary subplots (0.22 m^2) were systematically located within each fenced plot and its paired open plot during the autumn of 1976. Each subplot was measured for tree canopy cover (Pearson and Jameson 1967) and for basal area (Grosenbaugh 1952). The frequency and percent crown cover for vines, shrubs, and hardwoods up to 1.5 m high were recorded. Herbaceous species frequency and botanical composition by weight were estimated visually. Total herbage production was determined by clipping, ovendrying, and weighing, and was corrected for utilization by ocular estimate (Pechanec and Pickford 1937).

Paired *t*-test and regression procedures were used in the statistical analyses.

Results and Discussion

Grazing Effects

No grazing intensity tested significantly affected total herbage production as compared to the ungrazed control plots. However, grazing did affect the botanical composition (Table 1). The percent composition of pinehill bluestem (the most important cattle forage species in the area) was reduced by all grazing intensities. Conversely, carpetgrass (*Axonopus affinis*) greatly increased as grazing intensity increased. Carpetgrass was nearly absent under light or no grazing but increased to over 50% of the composition under heavy grazing. Composites declined under heavy grazing which differs from the results in

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Table 1. Herbage and tree characteristics under different grazing intensities.

	Grazing intensity					
	Light		Moderate		Heavy	
Measurement and taxa	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
Total herbage production (kg/ha)	666	814	540	557	336	325
Composition (% by weight)						
Grasses						
Pinehill bluestem (*Andropogon scoparius* var. *divergens*)	[1]37	53	[1]8	23	[1]2	21
Other bluestem (*Andropogon* spp.)	24	21	18	9	11	13
Panicums (*Panicum* spp.)	6	5	16	10	10	11
Paspalums (*Paspalum* spp.)	[2]t	1	2	3	1	2
Carpetgrass (*Axonopus affinis*)	t	0	[1]15	1	[1]51	1
Other grass	18	9	9	17	9	10
Total grasses	85	89	68	63	84	58
Grasslike plants	[1]2	2	12	6	7	8
Forbs						
Legumes	2	3	t	t	t	2
Composites	10	6	18	28	[1]5	26
Other forbs	1	1	2	3	4	6
Total forbs	13	10	20	31	9	34
Tree crown cover (%)	82	81	85	85	87	90
Tree basal area (m^2/ha)	26	28	24	27	31	35

[1] Significantly different from ungrazed conditions at 0.05 level.
[2] Less than 0.5%.

younger plantations (Pearson and Whitaker 1974b). The increase in carpetgrass may account for part of the decrease of composites.

Heavy grazing has previously been shown to reduce survival of young pines. In these stands of 13- to 16-year-old trees, grazing did not affect tree canopy cover. But heavily grazed plots did have significantly less tree basal area than adjacent ungrazed plots (Table 1), probably because of the reduction in tree numbers during the first year after planting (Pearson et al., 1971).

The effects of grazing intensity on shrub and vine crown cover could not be determined precisely because the prescribed burning schedule has maintained shrub and vine crown cover at such a low level (Table 2). Only on the moderately grazed range unit (whose ungrazed plots supported the most crown cover of the three range units) was the shrub and vine crown cover significantly reduced. The species principally affected was blackberry (*Rubus* spp.).

Although the herbaceous plants appeared to react in a consistent manner to grazing intensity, the effect of soils on shrub and vine cover may have to some extent outweighed the effect of grazing. Shrubs and vines appeared to be more abundant on the poorly drained, heavier-textured soils (Fig. 1). Distribution of soils and soil drainage conditions are the apparent reasons for the significantly greater abundance of shrubs and vines in the moderately grazed range unit. This greater abundance makes statistical detection of grazing impacts more likely. The results therefore should not be interpreted to mean that moderate grazing is necessarily more influential on shrubs and vines than other grazing intensities.

Overstory Effects

Herbage production has continued to be related to characteristics of the tree stand as these slash pine stands have grown. The relationship between herbage production and tree canopy cover, $Y=3582-35.76X$ (where Y=herbage dry weight in kg/ha and X=% tree canopy cover), was very similar to the relationship

Table 2. Shrub and vine crown cover (%) under different grazing intensities.

	Grazing Intensity					
	Light		Moderate		Heavy	
Taxa	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
Waxmyrtle (*Myrica cerifera*)	.01	.38	3.56	6.38	1.22	1.11
American beautyberry (*Callicarpa americana*)	.04	.01	.25	.00	.00	.00
Sumac (*Rhus* spp.)	.02	.12	.01	.59	.00	.00
Blackberry (*Rubus* spp.)	.36	.81	[1].28	4.08	.10	2.48
Huckleberry (*Vaccinium arboreum*)	.15	.32	.13	.14	.01	.00
Greenbrier (*Smilax* spp.)	.00	.00	.04	.08	.00	.01
Carolina jessamine (*Gelsemium sempervirens*)	.00	.00	1.22	.71	.00	.00
Alabama supplejack (*Berchemia scandens*)	.00	.00	.13	.03	.00	.00
Oaks (*Quercus* spp.)	.67	.19	.23	.12	.50	.18
Other shrubs	.22	.08	.04	1.98	.08	.02
Other vines	.00	.03	.00	.00	.00	.35
	1.47	1.94	[1]5.89	14.11	1.91	4.15

[1] Significantly different at 0.05 level from ungrazed conditions.

Fig. 1. *Variation in shrub and vine frequency: (a) lack of shrubs and vines on well-drained site; (b) abundance of shrubs and vines on poorly drained site.*

described when trees were younger and smaller (Pearson and Whitaker 1974b). The decreases from 1,099 kg/ha in 1971 to 540 kg/ha in 1976 demonstrates the decline in average herbage production as tree canopy cover increases. Basal area of the trees in these 13- to 16-year-old stands can also be used to predict herbage production, although the correlation coefficient is lower than when canopy cover is the predictor ($-.75$ for basal area and $-.81$ for canopy cover). The relationship is $Y=1539-34.96X$ (where X=tree basal area in m^2/ha). The differences in herbage production among range units are primarily related to variation in pine overstory canopy cover and basal area (Table 1).

Botanical composition also changed as tree basal area and canopy cover increased. On both grazed and ungrazed plots, forbs replaced grasses to a statistically significant degree between 1971 and 1976. Among grasses, pinehill bluestem and panicums (*Panicum* spp.) decreased most, while among forbs, composites increased most, except under heavy grazing.

Shrub and vine crown cover declined by nearly one-half from 1971 to 1976 (Pearson and Whitaker 1974b). This decline was likely caused by a reduction in shrub and vine vigor as the overstory pine canopy closed.

Conclusions

Grazing and tree canopy closure have predominant and predictable effects on rotationally burned herbaceous understory in the longleaf-slash pine-bluestem ecosystem. Removal of up to 60% of herbage by cattle does not cause measurable changes in total herbage production; however, increasing intensities shifts the plant composition from a predominance of bluestems toward a predominance of carpetgrass. Closure of the pine canopy results in an approximately linear decrease of herbage production, and an increase in proportion of forbs in the composition. While grazing and tree canopy closure appear to reduce shrub and vine cover, soils appear to also be very important in influencing the cover of these plants. Light to moderate grazing had no measurable effect on the regenerated pine stand.

The forage supply on southern pine forest range is thus greatly influenced by development of the tree stand. Available forage is normally reduced to less than one-half that of an open grassland within 10 years after slash pine is established (Pearson and Whitaker 1974a, Grelen 1976). Conversely, forage production can be expected to increase rapidly if the trees are thinned or completely harvested. Therefore, forage supplies often change substantially within a period of several years. In order to provide reasonable stability of livestock forage supplies, a variety of tree stand ages should be present within the boundaries of each livestock operation so that young tree stands with higher herbage yields will always be available. This requires a cooperative effort on long range planning for coordination of both grazing and forestry needs.

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Prescribed Burning: Vegetative Change, Forage Production, Cost, and Returns on Six Demonstration Burns in Utah.

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Abstract

Six demonstration burns were conducted between 1974 and 1976 as part of the Utah Rangeland Development Program. Big sagebrush (*Artemisia tridentata*), the target species, was essentially eliminated on the areas that were burned. Five of the six burns were seeded, with predominately crested wheatgrass (*Agropyron desertorum*). Despite the severe drought only one seeding was considered a failure. Forage production increased several-fold above preburn production and is expected to continue to increase as the grass stands mature. An economic analysis of the 1974 burn showed an internal rate of return of 17%. Great risks were associated with the use of fire. Extensive precautions were taken to minimize hazards but variable weather conditions in late summer greatly increased the chance of the fire escaping. Prescribed burning is inexpensive and effective in controlling big sagebrush when adequate safety precautions are taken.

Big sagebrush (*Artemisia tridentata*) and juniper (*Juniperous osteosperma*, and *J. monosperma*) have been the object of many shrub control efforts in the Western United States. These species were present in the climax condition, but overgrazing reduced many desirable species and fire suppression prevented the natural check of sagebrush and juniper (Wright 1977). Sagebrush increased to where it totally dominated much of its original range (Blaisdell 1953; Cottam 1947; Tueller 1973), and juniper increased in density and encroached upon sagebrush-bunchgrass communities (Blackburn and Tueller 1970; Plummer 1958; West et al. 1975). Grazing management alone will not check invasion of juniper nor appreciably improve deteriorated sagebrush and juniper communities (Blackburn and Tueller 1970; Burkhardt and Tisdale 1969).

The cost of traditional control methods of both sagebrush and juniper have increased tremendously. The effectiveness of cabling and chaining juniper have been questioned due to high cost and rapid reinvasion of young juniper trees (Aro 1971). Mechanical control of sagebrush is very expensive and is limited to level and relatively rock free sites. Pressure from environmental groups has limited the use of chemical control by the federal land management agencies. Fire is a natural part of the ecosystem and is very effective in controlling sagebrush and juniper. It is also relatively inexpensive (Nielsen and Hinkley 1973) if proper safety precautions are taken and environmental conditions are planned for.

Multiple use benefits have been enhanced by fire (Wright 1974). Forage production has increased following burning in sagebrush (Nielsen and Hinkley 1975; Uresk et al. 1976) and juniper (McCulloch 1969). Increased vigor of fire resistant grasses has been observed following burning (Daubenmire 1968). In some situations, water yields have been increased by the removal of sagebrush and juniper (Burkhardt and Tisdale 1969; Warskow 1977). With few exceptions, upland wildlife have an affinity for subclimax plant associations which fire is important in maintaining (Miller 1963).

Risks are incurred when using fire as a vegetation manipulation tool. Fire can readily escape and consume valuable forage, destroy fences and facilities, and leave the land owner liable for damages. (Pechanec et al. 1954). Accelerated erosion by both wind and water can occur until vegetative cover is reestablished (Pechanec et al. 1954; Wright et al. 1976). If undesirable sprouting shrubs and annual grasses are abundant in the vegetative community, burning may enhance the competitive advantage of these unwanted species and further degrade the site (Pickford 1932).

The key to effective burning is to select the climatic and environmental conditions in which fire will damage the target species without causing undue harm to the desirable species. Several articles have reviewed the effects of fire and burning conditions on a variety of the more important vegetative species (Blaisdell 1953; Britton and Ralphs 1978; Conrad and Poulton 1966; Wright 1971, 1972, 1977).

A series of demonstration burns was conducted throughout Utah in 1974 and 1976 in conjunction with the Demonstration Ranch Project and the Utah Rangeland Development Program. One objective of this program was to involve federal and state land management agencies in a coordinated planning effort and follow through with cooperative implementation of range improvements on private, state, and public lands. The Utah Division of Forestry and Fire Control, Bureau of Land Management (BLM), Forest Service, Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), Soil Conservation Districts, Utah Division of Wildlife Resources, and Utah State University Extension Service were involved in various aspects of planning, implementation, and follow-up management of the prescribed burns.

Description

Park Valley

Park Valley Hereford Corporation, located north of Park Valley in

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the northwest corner of Utah, was selected as the first Demonstration Ranch. The improvements were conducted on a broad, gently sloping alluvial flat at the base of the Raft River Mountains. The area had a long history of heavy grazing and was in poor condition. The range site was a semidesert shallow hardpan (40%) semidesert stony loam (60%) complex. Soils were a greyish-brown clay loam with a large percentage of fractured rock of granitic origin throughout the horizons. A hardpan existed about 30.5 cm (12 inches) in depth on the semidesert shallow hardpan site. Black sagebrush (*Artemisia arbuscula*) dominated this site with small amounts of bluebunch wheatgrass (*Agropyron spicatum*) and sandberg bluegrass (*Poa secunda*). Soil on the stony loam site was moderately deep (25—61 cm), and big sagebrush dominated with very little understory vegetation. Precipitation averaged 305 mm (12 inches) with 60% falling in the winter months. Elevation of the site was 1,646 m (5,400 feet). Toward the base of the mountain, juniper dominated the site but decreased as it spread into the sagebrush community on the alluvial flat.

A lightning-caused fire burned 73 ha (180 acres) of sagebrush and juniper in the west pasture in 1971. Crested wheatgrass was drilled into the ashes and a good stand was established. These results demonstrated the site potential and were instrumental in gaining agency and rancher approval to burn other suitable areas.

The first prescribed burn was conducted in September of 1974 within the west pasture. Three hundred and sixty-five hectares (880 acres) were actually burned and drilled to crested wheatgrass at the rate of 2.72 kg (6 lb) per acre. The second burn was conducted in August of 1976 within the middle pasture. Five hundred and sixteen hectares (1,275 acres) were burned and drilled to crested wheatgrass (*Agropyron desertorum*), alfalfa (*Medicago sativa*), and yellow sweet clover (*Melilotus officinalis*) at a rate of 2.72, 1.12, 1.12 kg per hectare (6,1,1 lb/acre), respectively. Four 30.5-m permanent line transects were installed in key areas on the semidesert stony loam site in each pasture prior to treatment to measure the percentage change in vegetative cover. Two 30.5-m permanent line transects were installed on the wildfire seeding to determine vegetative cover and measure the improvement that resulted from 2 years rest from grazing. Annual forage production was determined by the SCS ocular estimate in the west pasture prior to the burn in 1974 and by clipping a series of 2.93-m² (9.6 ft²) plots in subsequent years (1975-1977). Clippings were taken on the middle pasture in 1975 and 1976 prior to burning and in 1977, the first year after treatment.

The fire did not burn thick, mature stands of juniper. Sufficient understory vegetation to carry the fire was not present and the winds were light and would not sustain a crown fire. To finish treating the area, 356 ha (800 acres) of juniper were double chained in the winter of 1976. Crested wheatgrass, alfalfa, and yellow sweet clover were aerially broadcast on the site between chainings.

Scipio

Scipio West Bench Grazing Association is located on a gently sloping alluvial flat at the base of the Canyon Mountains about 6.4 km (4 miles) west of Scipio in central Utah. The range site was an upland stony loam in poor condition with a uniform stand of dense big sagebrush and very little understory vegetation. The elevation ranged between 1,890—2,073 m (6,2000—6,800 feet). Precipitation averaged 410 cm (16 inches) with 20—45% falling during the growing season. The soils were deep and well drained. The surface layers were dark grayish-brown loam between 15—25 cm (6—10 inches) thick with a high percent of cobbles. The surface soils were moderately textured with cobbly and coarse fragments increasing with depth.

The area was split into four 324-ha (800 acre) pastures, and a 30.5-m permanent line transect was installed in a key area within each pasture to determine percent change in vegetative cover. Three pastures were burned in July and August of 1976. Cool, humid weather terminated burning before all pastures were treated. The remaining pasture was double-chained with a modified Ely chain. The treated areas were aerially seeded to crested wheatgrass, intermediate wheatgrass (*Agropyron intermedium*), and yellow sweet clover and then covered with a chain.

Diamond Mountain

Diamond Mountain is located 40 km (25 miles) northeast of Vernal, Utah. Two neighboring ranchers conducted small prescribed burns in August 1976. The range site was mountain loam in fair condition with a dense stand of big sagebrush and a fair understory of perennial grasses and forbs. Elevation was about 2,500 m (8,200 feet) and precipitation averaged 51.0 cm (20 inches) with about 60% falling during the growing season. Soils are deep and well drained. The surface layers were a dark brown loam with clay loam subsurface layers.

To determine percent change in vegetative cover, a 30.5-m permanent line transect was installed in Walker pasture and two 100-toe-pace transects were taken before and after the Calder burn. Forage production prior to, and 1 year following both burns was determined by clipping a series of 2.93 m² plots within each pasture. The Calder burn was drilled to crested wheatgrass, Russian wildrye (*Elymus junceus*), alfalfa, and yellow sweet clover. The Walker burn was not seeded.

Altamont

The Myrin burn was conducted on a sandy river bottom 11 km (7 miles) southwest of Altamont in the Unita Basin in August of 1976. The big sagebrush was 1.2—2.1 m (4—7 feet) tall with no understory vegetation. Burning conditions were marginal and ⅓ of the area was left unburned. The unburned area was plowed with a rototiller and the entire area was drilled to crested wheatgrass, Russian wildrye, alfalfa, and yellow sweet clover at 4.48, 1.2, 1.2, 1.2 km per hectare, respectively. No pre- or post-treatment measurements were taken on this project.

Burning Prescriptions

The planned burning prescriptions for all six burns were similar: temperatures greater than 41.67°C (75°F), relative humidity 15—20%, and winds steady at 8—16 km per hour (5—10 mph). These conditions were necessary to get a large broadcast burn on the extensive acreages involved. Other prescribed burn preparations were outlined and followed (Ralphs et al. 1975).

Treatment costs were obtained from the ranchers, and the average cost of prescribed burning and associated improvements was determined. An economic analysis of the 1974 Park Valley west pasture project was conducted to determine the profitability of burning and seeding. An AUM was assumed equal to 1000 lb of forage and valued at $5. Proper use was 65%, and the lifetime of the seeding was assumed to be 20 years.

Results

Park Valley

Sagebrush was essentially eliminated on the areas within the fire guards that actually burned. Due to the release of native grasses and seeded species, grass and legume cover increased an average of 350% (Table 1). On a similar site in southern Idaho which had a good stand of understory grasses and forbs prior to burning, grass cover increased 90% after 4 years (Blaisdell 1953).

There were no pretreatment cover measurements for the 1971 wildlife and seeding but transects installed in 1974 and read in 1975 and 1977 revealed that the grass cover increased from 4.5% to 16% as a result of a 2-year rest. This attests to the benefits of periodic rest of heavily used seeded spring range.

Forage production increased from 112 kg/hectare (100 lb/acre) to an average of 703 kg/hectare (628 lb/acre) in the west pasture. The middle pasture forage incresed from 84 kg/hectare (75 lb/acre) to 521 kg/hectare (465 lb/acre) in the first year following the burn. There was essentially no forage production under the juniper stand prior to chaining, but forage production the first year after treatment was 157 kg/hectare (140 lb/acre). The 3-year average forage production on the wildfire seeding was 1,008 kg/hectare (900 lb/acre). On a slightly more favorable site in Central Utah, Cook (1966) obtained an average yield

Table 1. Range site, condition, vegetative cover, and forage production of prescribed burns and associated range improvements.

Location	Park Valley									Scipio				Diamond Mountain			
Project	Wildfire			West pasture burn		Middle pasture burn		Chaining		Burn		Chaining		Walker burn		Calder burn	
Year	1971			1974		1976		1976		1976		1976		1976		1976	
Range site	Semidesert stony loam			Semidesert stony loam		Semidesert stony loam		Upland stony hills-juniper		Upland stony loam		Upland stony loam		Mountain loam		Mountain loam	
Range condition				Poor		Poor		Poor		Poor		Poor		Fair		Fair	
	1974	1975	1977	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Vegetative cover (%)																	
Sagebrush	0	0	0	25	2*	28	.3*			22	0*	24.4	10.5	22	0	30	1
Other shrubs	1	2	6	4	2.5	15	4			8.2	1.1	.25	.5	0	1	3	2
Grass and legume	4.5	7.5	16*	4	13*	3	17.5			6	3	2.4	3.4	23	16	17	28
Forbs	6.5	9	.5	2.5	9.8*	5.5	5.3			.4	5.3	0	2.2	11	1	4	5
Forage production (kg/ha)		[a]1008		112	[a]703*	84	[b]521*	0	[b]157					258	[b]287	370	[b]411

* Statistically significant ($P<.05$).
[a] Average forage production 1975-1977.
[b] Forage production first year after treatment.

of 1,286 kg/hectare (1,148 lb/acre) from seeded crested wheatgrass.

Scipio

A very hot and intense fire resulted from extremely dry conditions and low humidities on the Scipio burn. Big sagebrush was entirely eliminated from all of the area that burned. The area was seeded, but the 1976-1977 drought was especially severe in central Utah, thus preventing establishment of the seeded species. Only 127 mm (5 inches) of precipitation fell between May of 1976 and August 1977, compared to the water year average of 410 mm (16 inches).

Sagebrush cover in the chained pasture declined from 24% to 10%. Due to lack of competition from native perennial grasses and failure of seeded grasses, the remaining sagebrush is expected to increase in vigor and regain dominance of the site.

Diamond Mountain

Approximately 80% of the area within the two Diamond Mountain projects actually burned. Some of the less dense stands of sagebrush did not burn and created a mosaic burn pattern. The resulting diversity of vegetation enhanced the aesthetic and wildlife values of the site. The remaining sagebrush also functioned as wind breaks and drifting soil and ash was deposited in and around these islands.

The Walker burn was the only one not followed by seeding. Grass cover decreased from 23% to 16%. Perchanec et al. (1954) also reported a decline in grass cover in the first 2 years following the burn, but it increased 60% by the end of 12 years. An almost pure grass stand, dominated by western wheatgrass (*Agropyron smithii*), remained and is expected to fill in and increse in density and cover in subsequent years.

The Calder site was drilled but seedling emergence was spotty. On the open ridges where there was little competition from native grasses, seeded species became established. However, in the swales, competition from native grasses prevented seeded species from becoming established. The combined effect of seeded species and increased native grasses improved the grass and legume cover from 17% to 28%. There was little increase in forage production the first year after treatment, but production is expected to increase as the grass stand matures.

Costs

Burning costs were separated into two categories: cash costs or actual expenditures by ranchers; and noncash costs, which included all of the donated equipment, manpower, and rancher's labor. The average cash cost of the prescribed burns was \$2.97/hectare (\$1.20/acre). The major component was fire line construction. Existing roads and natural fuel breaks were used as much as possible but some lines had to be constructed. The average cost was \$2.69/hectare (\$1.09/acre) or \$88/kilometer (\$142/mile) of line constructed. Other cash cost included fuel for ignition and miscellaneous labor expenses.

Labor was the largest component of the noncash costs averaging 5.07/hectare (\$2.05/acre). Equipment costs were \$3.63/hectare (\$1.47/acre). The total cost, including both cash and noncash costs, was \$11.32/hectare (\$4.58/acre). This approximates Nielsen and Hinkley's (1975) estimate of \$9.88/-hectare (\$4.00/acre), and is substantially lower than spraying, plowing, rotobeating, or chaining sagebrush.

All but one of the projects was seeded following the burn. Rangeland drills were used on four of the projects and acquired through cooperative agreements between the Soil Conservation Districts and the Forest Service or BLM. There were no rental costs for the drills, but parts and repairs were included in the seeding costs. The average cost of seed and drilling was \$17.79/hectare (\$7.20/acre). On the Scipio burn, the seed was aerially broadcast and then covered with a chain for \$24.71/-hectare (\$10/acre).

The costs of additional treatments to complete renovation of the pastures were considerably greater than burning. The cost of double chaining juniper and seeding to crested wheatgrass, alfalfa, and clover on the Park Valley project was \$44.62/hectare (\$18.06/acre). Double chaining sagebrush with an Ely chain and seeding on the Scipio project was \$33.88/hectare (\$13.71/acre). Rototilling sagebrush on the Altamont project cost \$24.71/hectare (\$10/acre).

An economic analysis of the Park Valley west pasture development, including the burn, seeding, fence, and water developments, gave an internal rate of return of 8%. The fencing was completed prior to the burns, and the water developments would have been installed had the burn not taken place. Without these additional improvements, the internal rate of return for the burning and seeding alone would have been 17%.

Problems Encountered

Weather conditions determine the behavior of a fire and consequently the effectiveness of a burn. The range of conditions necessary to obtain a good burn yet maintain safety margins are very narrow. Temperatures must be high enough to lower the mid-day humidity below 20%. Experience for these burns showed that the dampening effect at higher humidities prevented fire from spreading. However, in gullies and draws supporting dense stands of big sagebrush, sufficient heat was generated to preheat forward vegetation and overcome the suppressive effect of higher humidities. Conversely, humidities below 15% make vegetation very explosive and greatly increase the risk of a fire escaping.

A steady breeze is also necessary to carry a fire throughout the burning unit. Variable winds cause a fire to lose momentum, resulting in a patchy, nonuniform burn. On the other hand, whirlwinds or strong gusts can easily carry burning debris across the line and start a fire outside the burning unit. Unpredictable and inconsistent weather conditions increase burning hazards and raise manpower and equipment demands.

Wind erosion was another factor that caused severe problems in a nearby community. Blowing dust and ash annoyed residents close to the burn. However, where seedings were successful, wind erosion and blowing dust ceased after the first year. Pechanec et al. (1954) was in agreement that accelerated erosion was arrested 2 years after the burn.

The biggest risk encountered was that of fire jumping the line and escaping. There was not one burn that the fire did not jump at least once. Fortunately, most of the spot fires were contained before they escaped. One did get away and burned additional private, BLM, and Forest Service land and ranchers were faced with a large suppression bill.

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Control of Common Goldenweed with Herbicides and Associated Forage Release

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Abstract

Common goldenweed, an aggressive half-shrub, is rapidly increasing as a management problem on south Texas rangeland. Control with conventional foliar-applied herbicides has been erratic, with the extent of success apparently dictated primarily by growth conditions, especially soil moisture, at the time of treatment. After exceptionally high rainfall, applications of 2,4-D at 1.12 kg/ha in the spring or fall effectively controlled common goldenweed. When conditions were less than optimum for weed response, the addition of dicamba at 0.28 kg/ha with 2,4,-D or 2,4,5-T improved results compared to applications of phenoxy herbicides alone. Picloram was more effective than phenoxy herbicides or phenoxy/dicamba mixtures for common goldenweed control. Equal ratio combinations of picloram and 2,4,5-T were also effective and would be preferred where common goldenweed occurs with certain problem woody species. Within 1 year of treatment, 4.6 to 10.4 kg/ha of oven-dry forage was produced for each percentage unit of common goldenweed foliar cover removed by broadcast sprays. Successful treatments were effective for at least 3 years.

Common goldenweed (*Isocoma coronopifolia;* Compositae) is a perennial, suffrutescent half-shrub distributed throughout the western portion of the South Texas Plains (Correll and Johnston 1970). The species is closely related to the poisonous rayless goldenrod (*I. wrightii*) of the Trans-Pecos region. Common goldenweed forms a rounded canopy 4 to 8 dm tall and is heavily branched from the base. The foliage is resinous, aromatic, and unpalatable to livestock and wildlife. The bright yellow, rayless capitula appear in the fall, and large numbers of seed are produced.

Once considered a minor component of rangeland vegetation in southwest Texas, common goldenweed has increased dramatically in density and distribution during the last decade. Currently, the species dominates substantial portions of both native and improved rangeland (Fig. 1), especially where brush has been removed mechanically. Common goldenweed also occurs beneath dense cover of mixed brush (*Prosopis-Acacia*) typical of the region. The species appears to be a vigorous competitor and is considered by ranchers within the infested area to be as limiting as brush to forage production.

Attempts to control common goldenweed observed by the authors have often been unsuccessful. Response to commercial applications of 2,4-D [(2,4-dichlorophenoxy) acetic acid] has been erratic, and rates of 1.12 kg/ha or less have not been satisfactory. Foliar sprays of 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid], dicamba (3,6-dichloro-*o*-anisic acid), and picloram (4-amino-3,5,6-trichloropicolinic acid) were not effective at rates as high as 1.7 kg/ha near Zapata, Texas, after application in June (G.O. Hoffman, personal communication. Range Weed and Brush Control Specialist, Texas Agricultural Extension Service, College Station 77843). Herbicide treatments selected by range managers for common goldenweed control have been based on general responses of other range weeds rather than from specific research results. Also, since common goldenweed often exists within stands of mixed brush, there is a need for evaluation of herbicide treatments that will control the larger woody species as well as the half-shrub.

The objectives of this study were to evaluate the effectiveness of selected herbicides for control of common goldenweed, the influence of date of application on the weed's responses to herbicides, and the response of existing forage species to control of the weed.

Study Areas

The research was conducted in the western portion of the South Texas Plains, a physiographic province characterized by a moderate to dense cover of mixed brush. Annual rainfall generally ranges from 40 to 65 cm, and summer temperatures and evaporation rates are high (Carr 1967).

The first of three experiments was established 29 km northeast of Zapata, Tex., on rangeland which had been mechanically cleared of

Fig. 1. *A dense, continuous infestation of common goldenweed that has replaced buffelgrass 4 years after rootplowing and seeding in southwest Texas.*

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brush in the summer of 1969. Soils are principally a fine sandy loam of the Brennan series (Aridic Haplustalf). Catclaw acacia (*Acacia greggii*), honey mesquite (*Prosopis glandulosa* var. *glandulosa*), lotebush condalia (*Condalia obtusifolia*), blackbrush acacia (*Acacia rigidula*), and calderona (*Krameria ramosissima*) regrowth was apparent. At the time of brush clearing, the area was seeded to buffelgrass (*Cenchrus ciliaris*) and a good stand was established. However, by the summer of 1971 when herbicide studies were begun, the area was dominated by a dense cover of common goldenweed. Other grasses included blue panicgrass (*Panicum antidotale*), fringed signalgrass (*Brachiaria ciliatissima*), hooded windmillgrass, (*Chloris cucullata*), coast sandbur (*Cenchrus incertus*), and several species of *Setaria*. The herbaceous cover also consisted of a few forbs, primarily prairie coneflower (*Ratibida columnaris*), dogweed (*Dyssodia tenuiloba*), lazy daisy (*Aphanostephus ramosissimus*), and palafoxia (*Palafoxia rosea*).

A second experiment was established 45 km southwest of Hebbronville, Tex., approximately 16 km from the Zapata location. Soils are sandy loams similar to those at the Zapata site. The area had been rootplowed and seeded to buffelgrass in 1968. At initiation of this experiment, other grasses present included hooded windmillgrass, coast sandbur, knotgrass (*Setaria firmula*), red lovegrass (*Eragrostis oxylepis*), buffalograss (*Buchloe dactyloides*), and red grama (*Bouteloua trifida*). Forbs encountered were prairie coneflower, dogweed, lazy daisy, false ragweed (*Parthenium confertum*), ground cherry (*Physalis viscosa*), and winecup (*Callirhoe involucrata*).

A third experiment was established near LaPryor, Tex. Soils are saline with clay loam surface textures (Montell series, Entic Pellustert). The vegetation of the site is dominated by common goldenweed and scattered perennial grasses such as common curlymesquite (*Hilaria belangeri*), Arizona cottontop (*Digitaria californica*), plains bristlegrass (*Setaria macrostachya*), and red grama.

Materials and Methods

Herbicide treatments evaluated near Zapata included the butoxyethanol ester of 2,4-D at 1.12 kg/ha, alone and tank mixed with 2,4,5-T or dicamba at 0.28 kg/ha. The herbicides were applied in the summers of 1971 and 1972 (July 3 and July 4, respectively), in the fall of 1971 (October 2), and in the springs of 1972 and 1973 (April 2 and 3, respectively). Unusually high winds for an extended period precluded application in the fall of 1972.

Treatments evaluated near Hebbronville included 0.56, 1.12 2.24, and 4.48 kg/ha of the butoxyethanol ester of 2,4,5-T; 1.12 and 2.24 kg/ha 2,4,5-T mixed with 0.28 kg/ha dicamba; 0.28, 0.56, and 1.12 kg/ha of picloram as the potassium salt; and commercial 1:1 combinations of the triethylamine salts of 2,4,5-T and picloram at 0.56, 1.12, and 2.24 kg/ha (total herbicide). Herbicides were applied on March 3, April 1, May 1, and June 1 of 1972.

Treatments applied on June 5, 1975, near LaPryor were 2,4-D or dicamba at 1.12 and 2.24 kg/ha. Picloram was applied alone at 0.56, 1.12, and 2.24 kg/ha, and in the commercial 1:1 combination with 2,4,5-T at 1.12 and 2.24 kg/ha total herbicide.

Treatments were applied broadcast with a truck- or tractor-mounted boom sprayer to 7- by 30-m or 7- by 55-m plots. A set of untreated plots was included on each date. Treatments were replicated three times in a randomized complete block design.

When herbicides were applied near Zapata and Hebbronville, canopy cover of common goldenweed was recorded as foliar interception along a permanent 30.5-m line down the center of each plot. The line-intercept method (Canfield 1941) was used successfully to evaluate herbicide response of the closely related snakeweed (*Xanthocephalum sarothrae*) (Gesink et al. 1973). At 1 and 3 years after herbicide application, the same lines were used to estimate treatment effects by comparison of foliar cover within each plot before and after herbicide application. Goldenweed control is expressed as percent reduction of foliar cover at the Hebbronville and Zapata sites. At the location near LaPryor, three independent visual estimates of the reduction in live canopy in common goldenweed were utilized to reflect treatment effect at 6 months and 2 years after herbicide applications. Data were subjected to the arcsin $\sqrt{\%}$ transformation prior to analysis of variance (Steel and Torrie 1960). A splitplot data arrangement was used, with season or date of application as mainplot effect and herbicide treatment contributing subplot effect. Duncan's multiple range test was used to compare means at the 0.05 level of probability.

Rain gauges were maintained throughout the study at the Zapata and Hebbronville sites. Rainfall was not measured at LaPryor, but triplicate soil samples were collected at three depths (0 to 15, 15 to 30, and 30 to 45 cm) for gravimetric soil moisture determinations when herbicides were applied.

In late May 1973, herbaceous standing crop was estimated at the Zapata and Hebbronville locations by the weight-estimate-clipping method (Pechanec and Pickford 1937). Ten 1-m^2 sampling areas spaced 3 m apart were evaluated down the center of each plot. Each sampling area was divided into four subsamples. One subsample was harvested to ground level and the herbage was immediately weighed. Herbaceous standing crop in the remaining three subsamples was visually estimated. The clipped samples were dried at45°C for 48 hr, reweighed, and the visual estimates were adjusted accordingly. The relationship of percentage reduction in foliar cover of goldenweed (X) to standing crop of herbaceous material (Y) was determined using regression analysis. Although all plots were sampled, only data from plots treated in the spring were used for the regression.

Results and Discussion

Control of Common Goldenweed

Observations that 2,4-D is not effective for common goldenweed control were not verified by research results from near Zapata (Table 1). Regardless of season of application, 2,4-D applied at 1.12 kg/ha reduced foliar cover of common goldenweed by 89% or more 1 year after application. Other treatments (2,4-D with dicamba or 2,4,5-T at 0.28 kg/ha) were equally effective when applied in the spring or fall, but appeared less effective in the summer. Consequently, a significant season by treatment interaction was apparent. High variation in observed foliar interception, due to seasonal influences on common goldenweed canopy size, tended to mask differences in estimates of weed response between midsummer treatments and those in spring or fall. However, 3 years after applications in the spring or fall, common goldenweed foliar cover remained 72 to 90% less than pretreatment levels; the maximum reduction 3 years after summer treatment was only 50% (data not shown). During the 3-year period, foliar cover on untreated plots had increased by an average of 49% over the pretreatment levels, indicating continued worsening of the common goldenweed infestation on the Zapata study area.

At rates of 1.12 kg/ha or less, 2,4,5-T was not sufficiently effective against common goldenweed when applied on any of four dates in the spring near Hebbronville (Table 2). Foliar cover was significantly reduced by application of 2,4,5-T at 0.56 kg/ha only on May 1 (44%). Control of common golden-

Table 1. Percent decrease in common goldenweed foliar cover 1 year after application of 1.12 kg/ha of 2,4-D alone and combined with 0.28 kg/ha of dicamba or 2,4,5-T near Zapata, Texas.

Herbicides	Seasons of treatment[1] Fall	Spring	Summer	Herbicide average
None	0 c	0 c	0 c	0 s
2,4-D	98 a	91 a	89 a	93 r
2,4-D + dicamba	98 a	90 a	40 b	76 r
2,4-D + 2,4,5-T	85 a	94 a	67 ab	82 r
Season average[2]	94 y	92 y	65 z	

[1] Means followed by the same letter do not differ significantly ($P = 0.05$).
[2] Averages of herbicide-treated plots only.

Table 2. Percent decrease in common goldenweed foliar cover 1 year after application of 2,4,5-T alone or in combination with dicamba near Hebbronville, Tex., in 1972.

Herbicides	Rates (kg/ha)	Treatment dates[1] March	April	May	June	Herbicide average
None	—	0 e	0 e	0 e	0 e	0 u
2,4,5-T	0.56	0 e	0 e	44 c	7 e	26 t
2,4,5-T	1.12	72 b	56 bc	54 bc	20 d	51 s
2,4,5-T	2.24	80 ab	82 ab	79 ab	31 cd	68 s
2,4,5-T	4.48	98 a	98 a	99 a	85 a	95 r
2,4,5-T + dicamba	1.12 + 0.28	60 bc	71 b	75 b	76 b	71 s
2,4,5-T + dicamba	2.24 + 0.28	98 a	86 a	91 a	83 ab	90 r

[1] Means followed by the same letter do not differ significantly (P=0.05).

weed was improved where 2.24 or 4.48 kg/ha of 2,4,5-T were applied, apparently in proportion to herbicide rate. However, only the 4.48 kg/ha rate provided consistent control, reducing the weed foliar cover by an average of 95%.

Addition of 0.28 kg/ha of dicamba to 2,4,5-T generally enhanced common goldenweed control near Hebbronville, compared to applications of 2,4,5-T alone (Table 2). The advantage of the combination over 2,4,5-T alone was particularly apparent in response to June applications. Common goldenweed response to 2,4,5-T alone at 1.12 or 2.24 kg/ha decreased sharply from the May to the June application (54 to 20% and 79 to 31%, respectively), whereas no difference among dates was apparent when 0.28 kg/ha dicamba was included. Apparently, the spring period in which common goldenweed can be successfully treated with 2,4,5-T is extended by at least 1 month by addition of dicamba at a relatively low rate.

Piclorm at 0.28 kg/ha did not control common goldenweed near Hebbronville (Table 3). However, sprays of picloram at 0.56 kg/ha in March or May effectively controlled the weed. Applied at 1.12 kg/ha, picloram reduced foliar cover by 96 to 99% after 1 year, compared to pretreatment cover, regardless of date of application. Rates of 2.24 and 4.48 kg/ha of 2,4,5-T were required to give equivalent control levels (Table 2).

Equal ratio combinations of 2,4,5-T and picloram were usually more effective than the same rates of 2,4,5-T applied alone (Tables 2 and 3). Application of 0.56 or 1.12 kg/ha of picloram in combination with the same amount fo 2,4,5-T generally resulted in control levels similar to those obtained with the same rate of picloram applied alone. Common goldenweed grows in association with mixed brush on the South Texas Plains, and the combination of 2,4,5-T and picloram is also effective for control of mixed brush (Scifres et al. 1977). The herbicide combination should serve a dual purpose where mixtures of goldenweeds and brush present a problem, if sufficient herbicide penetrates the woody canopy and is deposited on the weed substratum.

Compared to foliar canopy reductions 1 year after treatment near Hebbronville, control levels averaged about 20% less at 3 years after 2,4,5-T was applied, and about 10% less on picloram-treated plots. For instance, common goldenweed control averaged 98% across all dates at Hebbronville after 1 year and 75% 3 years after applications of 4.48 kg/ha of 2,4,5-T. In plots treated with picloram at 1.12 kg/ha, weed control decreased from 97% after 1 year to 89% after 3 years. After 3 years, foliar cover on untreated plots at Hebbronville averaged 38% higher than the initial (1972) levels.

Applications of 2,4-D near LaPryor in 1975 were less effective in controlling common goldenweed (Table 4) than were applications of the same herbicide in the summer of 1971 near Zapata (Table 1). Dicamba was more effective than 2,4-D applied at the same rates; applied at 2.24 kg/ha, dicamba reduced common goldenweed canopies by 74% (Table 4). Picloram was also less effective near LaPryor than at other locations. The higher rate, 2.24 kg/ha, was required (Table 4) for control approaching that obtained with lower rates near Hebbronville (Table 3). Few differences were noted in estimates of weed response 6 months and 2 years after treatment at the LaPryor location.

Comparison of the results of similar treatments applied in the three experiments substantiated ranchers' and commercial appliers' reports of the erratic nature of common goldenweed response to broadcast sprays. In this study, responses to 1 kg/ha of 2,4-D ranged from 98% canopy reduction in 1971 and 1972 near Zapata to 11% reduction in 1975 near LaPryor. Weed response in the Hebbronville experiment was intermediate.

Although other factors may also be important, soil moisture availability appeared to strongly influence common goldenweed response to sprays. During the 18 months that rain gauges were maintained at the Zapata and Hebbronville study areas

Table 3. Percent decrease in common goldenweed foliar cover 1 year after application of 2,4,5-T and picloram alone or combined in equal ratios near Hebbronville, Tex. in 1972.

Herbicides	Rate[1] (kg/ha)	Treatment dates[2] March	April	May	June	Herbicide average
None	—	0 e	0 e	0 e	0 e	0 t
Picloram	0.28	6 e	0 e	0 e	0 e	2 t
Picloram	0.56	100 a	72 b	96 a	71 b	85 r
Picloram	1.12	96 a	97 a	99 a	96 a	97 r
2,4,5-T + picloram	0.28	12 de	0 e	20 d	0 e	8 t
2,4,5-T + picloram	0.56	47 c	20 d	58 bc	31 cd	39 s
2,4,5-T + picloram	1.12	92 a	89 a	89 a	74 b	86 r
2,4,5-T + picloram	2.24	92 a	94 a	98 a	96 a	95 r

[1] Rates of the commercial combination are given as total herbicide applied.
[2] Means followed by the same letter do not differ significantly (P = 0.05).

Table 4. Percent canopy reduction of common goldenweed 6 months after foliar applications of various herbicides in June 1975 near LaPryor, Tex.

Herbicides	Herbicide rate (kg/ha)[1]	
	1.12	2.24
2,4-D	11 d	43 c
Dicamba	33 c	74 a
Picloram	56 b	86 a
2,4,5-T + picloram (1:1)	28 cd	88 a

[1] Means followed by the same letter do not differ significantly ($P = 0.05$).

Table 5. Standing crop of oven-dry forage (kg/ha) in May 1973 after applications of 2,4-D at 1.12 kg/ha alone or combined with 0.28 kg/ha of dicamba or 2,4,5-T near Zapata, Tex.

Herbicides	Seasons of treatment[1]			Herbicide average
	Fall	Spring	Summer	
None	869 b	379 a	896 b	715 s
2,4-D	1034 c	873 b	1313 c	1073 r
2,4-D + dicamba	1270 c	1717 d	840 b	1276 r
2,4,-D+2,4,5-T	952 bc	1399 c	791 b	1047 r

[1] Means followed by the same letter do not differ significantly ($P = 0.05$).

(October 1971 to March 1973), 190 cm of rain were recorded at the Zapata site, where weed susceptibility was high. At the Hebbronville site, where weed response was comparatively lower, 91 cm of rain were recorded during the same period, and the majority fell during fall months in 1971 and 1972. Soil moisture conditions were not favorable for growth when applications were made in early March, April, May, and June near Hebbronville. Average annual rainfall for the 18-month period is 58 cm at Zapata and 72 cm at Hebbronville (Anon. 1973).

Common goldenweed was especially tolerant of broadcast sprays in the LaPryor experiment. Although rainfall was not measured, soil moisture content on the day of treatment was 7.8% in the surface 15 cm, 9.6% at a depth of 15 to 30 cm, and 10.0% at the 30 to 45 cm depth. Soil water availability was low, in view of the high tensions at which water is held in a clay loam soil.

Similar variation among years and locations in response of the closely related range weed *Ericameria austrotexana* has been reported (Mayeux and Scifres 1976). A comparison of environmental conditions during herbicide applications suggested that lowered *Ericameria* susceptibility was associated with moisture stress. Rainfall prior to treatment or the presence of adequate soil moisture is a demonstrated requirement for satisfactory control of other similar species (Sperry 1967; Mohan 1973). The dependence is probably related to a requirement for rapid vegetative growth and associated physiological activity. Periods of rapid stem elongation of Drummond's goldenweed correspond closely to brief periods of high extratable soil water (Mayeux and Scifres 1978).

Forage Production Following Control of Common Goldenweed

The amount of herbaceous standing crop in 1973 was directly related to the percentage reduction in foliar cover of common goldenweed at both locations (Zapata, r=0.91; Hebbronville, r=0.64). Correlation coefficients were significant at the 0.05 probability level. The relationships were linear, which suggests that maximum potential forage production was not approached at either location.

At the Zapata location, herbaceous standing crop was increased by 10.4 kg/ha for each 1% reduction in common goldenweed cover. Without common goldenweed control, the calculated standing crop (Y intercept) was 449 kg/ha and predicted production after complete control was 1,489 kg/ha. Standing crop on untreated plots, as estimated by the weight-estimate-clipping method and averaged across season of treatment, was 715 kg/ha (Table 5). The overall average standing crop of forage on treated plots was 1,132 kg/ha. The maximum standing crop of forage at Zapata, 1,717 kg/ha, followed spring application of the 2,4-D/dicamba combination.

Near Hebbronville, calculated yield with no herbicide applied was 645 kg/ha. Standing forage was increased by 4.6 kg/ha for each 1% reduction in foliar cover of common goldenweed. The predicted standing crop after elimination of the weed would be 1,105 kg/ha. Highest actual yield on this site, 1,483 kg/ha, followed application of 1.12 kg/ha of picloram on April 1, 1972.

Conclusions

Control of common goldenweed with broadcast sprays of herbicides is feasible and can result in substantial increases in forage production. Satisfactory results may be obtained by spraying in the spring or fall. Since adequate soil moisture for plant growth is particularly important for control, regardless of season, spraying should be done only during periods of high rainfall.

When moisture conditions are near optimum for vegetative growth, 1 kg/ha of 2,4-D is adequate to control common goldenweed. However, given the low frequency of occurrence of rainfall in south Texas comparable to that measured at the Zapata study site in 1971 and 1972, more consistent results under conditions of normal spring and fall precipitation would require the use of 2 kg/ha. Results of spraying when conditions for weed response were less than optimum were also improved by the addition of 0.28 kg/ha dicamba to the phenoxy herbicide. Picloram and the 1:1 combination of picloram and 2,4,5-T were more effective against common goldenweed than were the phenoxy herbicides alone and especially would be preferred if brush species were present.

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Comparison of Fecal, Rumen and Utilization Methods for Ascertaining Pronghorn Diets

A.D. SMITH AND L.J. SHANDRUK

Abstract

Fourteen male pronghorn (*Antilocapra americana*), two in each of seven spring and summer months, were killed to obtain rumen and fecal matter for comparing methods of determining diets. They came from a herd confined to the Desert Experimental Range in southwestern Utah. Animals were killed only after they had completed their early morning grazing period. Plant material was removed from the rumens and rectums, fresh feces were collected from the feeding site, and forage utilization and production estimates were made there. Diets as indicated by the four data sources—rumen, intestinal feces, site feces, and utilization—varied with individual animals from close to little agreement, a not unexpected result in view of food availability and selection. Fewer plant species were identified by fecal analysis than were found in the rumen; even fewer species were recorded by utilization estimates. This indicates that fecal analysis may be less accurate than rumen data but more so than those based on plant utilization. Validation tests of the fecal method conducted with mule deer (*Odocoileus hemionus*) fed known diets showed substantial differences with individual species in the amounts fed and the amounts indicated by fecal analysis. Only in the case of the single grass species fed was there close agreement; browse and forb species differed greatly.

Effective management of wild ruminants and their habitat depends upon a knowledge of plants selected and the composition of the diet at each season. All methods for determining animal diets have disadvantages. Analyses of rumen contents necessitate sacrificing animals unless fistulated animals are available, a costly and often troublesome procedure. Moreover, biased estimates may result from rumen samples because plants have different rates of digestibility and disappearance from the rumen. Utilization estimates, usually ocular, are subject to observer error and personal biases. Utilization is difficult to detect when use is light, as it often is with game animals; and when more than one herbivore is present it may not be possible to separate their effects. There are limited opportunities for observing wild animals feeding at close range. In dense vegetation, determining the plant being utilized is nearly impossible. Use of tamed animals can minimize some of these difficulties, but they provide limited and possibily unrepresentative sampling.

Fecal analysis is increasingly advocated to avoid the disadvantages of other methods for determining diets of free-ranging ruminants present. Fecal samples can be obtained without intensive animal observations, topography or dense vegetation is no hindrance, animals need not be killed or their normal feeding habits disrupted, and animal movements are unaffected. For these reasons the fecal method may be especially useful for determining the food habits when rare or endangered ruminants are involved.

It seemed worthwhile to inquire into the utility of the fecal analysis technique for determining pronghorn diets because: populations are sparse in Utah making direct observation difficult; their habit of defecating on roadways makes fecal collection comparatively easy even though animals are scattered widely; grass makes up a small part of their diets and past research in which the fecal technique has been used has dealt with animals whose diets were primarily grass.

The histological approach to food habits utilizing epidermal fragments in feces was first attempted by Dusi (1949) to determine food habits of rabbits by adapting a technique used by Baumgartner and Martin (1939) to analyze stomach contents from squirrels. Martin (1955) in Scotland and Croker (1959) and Hercus (1960) in New Zealand used fecal analysis to ascertain sheep diets. Voth and Black (1973) used the technique with mountain beaver (*Aplodontia rufa*) and Owen (1975) applied it in waterfowl studies.

Despite the wide use of fecal analyses in food habits research, controlled tests using known diets are comparatively few. Storr (1961) used the fecal analysis technique to determine kangaroo diets using captive animals fed known diets. There was no significant digestion where epidermal tissue was well encased in cutin; a condition existing only in perennials. Annuals did not fill this requirement and the method did not "cope satisfactorily" with them.

Stewart (1967) fed known quantities of eight grasses to seven East African game species—six ruminants and one nonruminant. Counts of epidermal fragments were judged invalid because of their differential size. Determination of areas of epidermis or tabulations by point counts provided better indexes, but even then significant differences were found from the amounts ingested. Zyznar and Urness (1969) fed known quantities of shrub and herbaceous plant species to captive mule and white-tailed deer. Only a small percentage of the fecal material examined could be identified, leading them to question the accuracy of the method, although their techniques were less sophisticated than those developed since.

Free et al. (1970) collected forage samples from esophageally fistulated steers and fed the samples to sheep. They reported substantial agreement between the weights of grass species found in the esophageal samples and those in the fecal samples of steers and sheep. Forbs were less readily identifiable al-

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though they were present in only small amounts.

Hansen (1971) claimed close agreement between the composition of ingested and fecal material of wild sheep, but no data on plant species were included. Casebeer and Koss (1970) reported similarity between the stomach contents and fecal material of wildebeest (*Connachaetes taurinas*), zebra (*Equus burchelli*), hartebeest (*Acelaphus buselaphus cokii*), and cattle; but examination of their data show *Themeda triandra* was consistently over- or under-estimated depending on the animal and the season—in one case more than 200%. Anthony and Smith (1974) compared rumen and fecal samples from both mule and white-tailed deer and found some highly significant differences.

Marshall (1969) warned of the difficulties encountered in the use of microscopic fecal analysis for quantifying herbivore diets. Slater and Jones (1971) reported that white clover in quantities up to 20% of the diet of sheep did not show up in the feces, and a grass species (*Setaria sphacelata*) which comprised 27 to 38% of the diet of three heifers yielded only 1 to 4% in the feces. *Siratro*, a legume, the only other plant in the diet suffered excessive fragmentation, which depressed the percentage of grass.

More recently, Jacobs (1973) reported results and problems of the fecal technique with pronghorn. He found smooth bromegrass (*Bromus inermis*), white sweetclover (*Melilotus officinalis*), and big sagebrush (*Artemisia tridentata*) were underestimated by the fecal technique. Westoby et al. (1976) concluded after examining ground contents from stomachs of jackrabbits (*Lepus californicus*) that the microscopic examination of fragmented material was ill suited to diets containing desert (northern) shrubs.

The primary objectives of this study were to:

1. Compare fecal analyses, rumen analysis, and utilization estimates as methods for obtaining quantitative estimates of antelope diets which are primarily of species other than grass.
2. Determine if various plant species representative of antelopes' diets are differentially recognizable after passing through the digestive system of an animal.

Methods

The study was done in two phases. One involved killing pronghorn antelope from an experimental herd confined within an enclosure on the Desert Experimental Range in southwestern Utah, a branch of the Intermountain Forest and Range Experiment Station, U.S. Forest Service. Rumen and fecal materials were obtained from the killed animals by sampling the contents of the rumen and rectum. Two animals were taken each month from July to November in 1970, and in 1971 two animals were killed in April and two in June. A feared shortage of males—all animals taken were males—caused us to skip a planned May collection.

Animals were collected only after a herd of pronghorn numbering from a few to several animals had been observed to occupy and feed on a site for several hours. Forage utilization and production estimates for calculating diets were made at the feeding site, and fresh-appearing fecal material was collected from the immediate area.

Four different sources of data were thus available for comparison: rumen material, intestinal feces, feces collected from the ground, and vegetation estimates. Obviously these material sources were not entirely comparable, but no sample from an individual animal is comparable to that from another unless both are restricted to the same forage choices, an impossibility with free-ranging animals.

The rumen materials were analyzed by gravimetric point frame (described by Chamrad and Box 1964) and the microscopic point method. The microscopic-point count was accomplished by passing slides containing ground material under the objective of a compound-binocular microscope so that the cross hair described five equally spaced transects through the mount. Fragments encountered by the cross hair were identified and tabulated (Shandruk 1975). The point frame and microscopic point methods provided counts of fragments which were converted to percentage frequency. In this paper the means of the three methods were used to represent rumen analysis. To avoid observer biases all the samples were analyzed by one technique at a time in this order: rumen, intestinal fecal, and site fecal.

The dried fecal materials were ground through a 40-mesh screen. The ground material was preliminarily treated as described by Storr (1961), Williams (1969), and Cavender and Hansen (1970). None of these procedures proved suitable, as the forb species in particular lost their distinguishing characteristics, making identification questionable. Furthermore, the procedures were too complicated and time consuming. The procedures used combined features of several techniques reported in the literature. A mixture of 10% nitric and chromic acids (1:1) was used to digest the ground (40-mesh screen) samples and free the epidermal fragments. Digestion lasted 12 hours. Safarin-0 and crystal violet stain were successively used as staining media. Stained materials were mounted on microscopic slides in Karo mounting medium. The procedures followed are described in detail by Shandruk (1975).

Although comparing the values obtained from the fecal material with those obtained by other methods provided a rough measure of the reliability of the fecal analysis technique, no definitive assessment could be made from these comparisons alone. Accordingly, a feeding test was devised where there was control over the species ingested. The test was conducted in May with green herbaceous forage. No pronghorn were available, so captive mule deer were used. Five plant species were included in the diet—two browse species, two forbs, and one grass (Table 3). The mixture used was formed to simulate the kinds of forage used by pronghorn. Only the browse species were identical to species found in the area from which the pronghorn were collected; the herbaceous species, however, were similar to or were of the same genera as plants available to them.

Two mule deer were confined to individual pens and fed ad libitum of the five species for several days to ascertain how much of each they would eat. During the test period, the five species were fed in the same proportions they were consumed in the preliminary period, and the total amount offered was kept just below the level of consumption we had observed. Consequently, virtually all of the offered material was consumed each day throughout the 10 days of the test. To compensate for the time required for material to pass through the digestive tract, fecal material was compared to forage intake observed 48 hours previously (Mautz and Petrides 1971). Since intake was regulated by limiting amounts of each plant in the mix, this precaution was taken primarily to avoid any pretest influence, although in view of the findings of Eng et al. (1964) 48 hours may be insufficient to eliminate all pretest materials. Samples for analysis were composited from all pellet groups deposited each day.

Results

Standard deviation indexes ($I = \frac{\Sigma(d)^2}{n-1}$, Hansen 1971) and coefficients of determination (r^2) were calculated by making paired comparisons of the individual results obtained by the four methods (Table 1). A low index of deviation indicates agreement; a high coefficient of determination does likewise. By both of these indexes, the order of the first three paired comparisons are identical. The other three pairs appear in inverse order, but the differences in each case are small and provide little basis for judgments. Closest agreement was found between diets determined by fecal material collected at a feeding site and utilization estimates made at the same location. This high agreement might have been predicted, for by either method sources of variation are minimized. The samples represent selection of more than a single animal; more than one day's selection was represented at

Table 1. Comparisons of four methods of diet determination of 14 antelope.

	Deviation index	Determination value	Coefficient rank
Site feces × utilization	5.72	0.766	1
Rumen × intestinal feces	8.90	0.605	2
Rumen × utilization	10.62	0.507	3
Intestinal feces × site feces	11.54	0.394	6
Rumen × site feces	11.81	0.398	5
Intestinal feces × utilization	11.99	0.444	4

least on some feeding sites, and on occasion selection was being made from the same plant mix.

Rumen analysis agreed most closely with fecal material from the intestines; rumen analysis and utilization estimates were in third place.

Comparisons based on individual animals are more revealing. In 7 of the 14 individual samples, the results obtained from the rumen agreed very closely both as to species identified and percentage in the sample with the intestinal feces analysis. Since there may be considerable lag between food ingestion and its appearance in the lower intestine, this close agreement indicates constancy in food selection.

In six of the samples, site feces and utilization estimates were very similar and differed somewhat from other methods. Site feces was often intermediately comparable between rumen and intestinal feces on the one hand and vegetation utilization on the other. In one instance site feces agreed most closely with the rumen sample, and intestinal feces was intermediate between rumen and utilization, as it was in four other instances. In four instances rumen diets stood alone; in five instances forage utilization figures differed from all other analytical methods tested.

One measure of the accuracy of the technique for ascertaining diet composition is the number of species identified in the sample; the more species found the more sensitive the method, assuming accuracy in identification. By this criterion, the methods are in descending order rumen, intestinal feces, site feces, and utilization estimates, with mean number of species per sample of 8.7, 8.6, 7.0 and 5.9, respectively. Surprisingly, fewer species were identified in fecal material collected from the ground than in fecal material taken from the intestines. That utilization estimates identified fewer species is not surprising, for the possibility of overlooking light use on quantitatively less important species is high. Moreover, certain plants which readily disarticulate upon being grazed leave almost no visual evidence that cropping has taken place.

The two animals killed at each collection date were insufficient to provide an adequate sample because of individual preference and nonuniformity of vegetation throughout the enclosure. By aggregating the observations from all 14 animals over the entire period, we can in effect enlarge the sample and iron out day-to-day variations. When this was done, there was a high degree of agreement among all methods. In a few instances the percentages differ, but differences are not large, and the results, as shown by the ordination, are almost identical for the

Table 2. Comparison of the diets of male antelope in southwestern Utah for seven periods throughout the summer months as determined by four methods.

	Rumen		Intestinal feces		Site feces		Utilization		Mean	
	Percent	Rank	Percent	Rank	Percent	Rank	Percent	Rank	Percent	Rank
Browse										
Prunus fasciculata	21.7	1	24.3	1	25.2	2	22.5	2	23.4	1
Artemisia nova	17.4	2	17.7	2	27.1	1	27.5	1	22.4	2
Xanthocephalum sarothrae	11.8	3	12.4	3	8.5	4	6.8	4	9.9	3
Artemisia spinescens	7.3	6	7.4	5	8.5	3	10.0	3	8.3	4
Ephedra nevadensis	2.5	10	3.9	8	3.2	8	4.3	7	3.5	8
Juniperus osteosperma	8.0	4	5.7	6	0.1	21	0.1	21	3.5	9
Brickellia oblongifolia	6.3	7	3.9	7	0.8	14	1.3	12	3.1	10
Tetradymia nuttallii	0.7	13	2.0	12	2.5	9	2.9	10[a]	2.0	12
Atriplex confertifolia	1.9	11	2.5	11	2.1	10	1.1	13[b]	1.9	13
A. canescens	0.5	17	1.2	15	0.3	19	0.7	16[c]	0.7	15
Cercocarpus intricatus	0.4	18[d]	0.5	16	0.5	18	0.2	20	0.4	18
Cowania stansburiana	0.3	20	0.4	17	0		0.7	17[c]	0.4	19
Chrysothamnus spp.	T	27	0		0.1	20	0		T	27[e]
Total browse	78.7		81.9		78.8		78.1		79.5	
Forbs										
Sphaeralcea spp.	3.4	9	7.5	4	6.6	5	5.1	6	5.6	5
Salsola kali var. *tenuifolia*	5.4	8	3.5	10	5.1	6	6.4	5	5.1	6
Eriogonum spp.	7.7	5	3.8	9	2.0	11	2.9	9[a]	4.1	7
Enceliopsis nudicaulis	0.8	12	1.3	14	1.6	12	1.1	14[b]	1.2	14
Oenothera canescens	0.3	21	0		0.6	16	1.8	11	0.7	16
Chenopodium album	0.5	16	0.3	18	0.5	17	1.1	15[b]	0.5	17
Euphorbia ocellata	0.2	22	0.3	19	0.6	15	0.3	19	0.3	20
Hermidium alipes	0.1	25[f]	0.3	20	1.0	13	0		0.3	21
Penstemon nana	0.6	15	T	22	0		0		0.2	22
Hymenopappus filifolius	0.2	23	0		0		0.4	18	0.1	23
Chaenactis macrantha	0.4	19[d]	0		0		0		0.1	24
Cryptantha spp.	0.1	26[f]	0.1	21	0		0		0.1	25
Haploppapus nuttallii	0.1	24	0		0		0		T	26[e]
Total forbs	19.8		17.1		18.0		19.1		18.4	
Grass	0.7	14	1.7	13	3.3	7	3.0	8	2.2	11

[1] Entries followed by letters indicate identical values within columns; T = trace.

major forage species (Table 2). This suggests that if sufficiently large samples were taken, any of the methods could be expected to be in close agreement.

The results of the controlled feeding tests with deer do not confirm the reliability of the fecal technique. No species appeared in percentages closely approximating its occurrence in the diet (Table 3). Sagebrush (*Artemisia tridentata*) and juniper (*Juniperus osteosperma*) were greatly overestimated in the fecal analysis. Both forbs, mulesear (*Wyethia amplexicaulis*) and desert parsley (*Lomatium dissectum*), were underestimated considerably. Kentucky bluegrass (*Poa pratensis*) came closer to agreement, but even it was overestimated by 23%. A paired *t*-test on the fecal-diet estimate comparing the results of the two deer showed highly significant differences ($P \leq .01$) for all species fed except *Lomatium*.

A similarity index was calculated using Kulczunski's mathematical index of similarity (Hansen 1971) $SI = \frac{2w}{a+b}$ where w is the lowest value of percent composition of the actual intake and the dietary estimates and $a+b$ is the sum of the intake estimate and the fecal estimate (Table 3). The index should equal 100% if the fecal estimate equaled the amount of forage fed (intake estimate). Hansen (1971) considers an index of 85 or better an indication that samples are very much alike. Only with bluegrass did the index of similarity exceed 85%, notwithstanding a paired *t*-test showed a highly significant difference between the amounts of bluegrass in the food feces. These results, though limited, indicate that there is a differential disappearance of epidermal fragments among species.

Table 3. Comparison of percent composition of diets of two mule deer and percentage identified in feces on a dry weight basis.

Species	Percent of diet fed	Diet estimate using fecal analysis	*t*-values	Similarity index, percent
Artemisia tridentata	9.45	28.83	19.71**	46.57
Wyethia amplexicaulis	39.52	24.57	13.30**	76.67
Lomatium dissectum	33.03	22.33	9.43	80.69
Poa pratensis	17.67	21.66	4.53**	89.91
Juniperus osteosperma	0.34	3.07	7.66*	20.65

**Significantly different at .01 level.

Discussion

The results we obtained suggest the claims for accuracy of the fecal analysis technique made by some investigators are overstated. In those studies where close agreement between observed intake and fecal fragments identified have been reported, grasses provided the sole or major part of forage ingested. Similarities between species with respect to cutinization, fragmentation on digestion, rate of digestion, and ratio of epidermis to volume of plant tissue could thus be expected to be quite similar among species. When dissimilar plants such as forbs and browse have been involved, the results have been disappointing (Jacobs 1975; Slater and Jones 1971; Westoby et al. 1976). Dunnet et al. (1973) found different digestibilities (as determined by "persistence indexes") due to plant species, individual animal, and feeding trial. Voth and Black (1973) ascertained that among 20 species eaten by mountain beaver the ratios of fecal fragments identified to the weight of material consumed varied from 0.9 to 14.6. No grasses were included nor does it appear that the fecal material was ground prior to analysis, a procedure that might be expected to reduce variability in the size of epidermal fragments, and hence, the range of fragment to weight ratios.

The marked differences in the results from individual animals as shown by the method of analysis used—rumen material, fecal material, or utilization estimates of vegetation—are not surprising, since to a considerable extent they did not represent samples from the same population. Had the animals been confined to a homogeneous plant community for a period of 2 or 3 days, one could have expected greater agreement. In fact there were several factors which affected agreement among the samples obtained. In some cases there was evidence that the site where animals were located and from which samples were obtained had been occupied for a day or more. Under these conditions, the results could be expected to be similar, and any differences would reflect the method of analysis. If, however, animals had just moved to the site from grazing another plant community, the fecal material, whether obtained from the intestine or picked up on the site, would represent vegetation from areas previously grazed and which may have been unlike that found at the collection site. Rumen material and intestinal feces represent a much shorter feeding interval than other data sources.

It is difficult to explain why utilization and rumen data were not more often similar, for they ought in most cases to have come from the same population. We killed animals only after they had been observed feeding for some time; hence estimates of forage removal should have matched material in the rumen unless the animals had fed elsewhere before we located them, in which case items other than those on site could have been ingested. In addition, coarser material may be retained in the rumen, thus exaggerating its importance.

Although there are reasons, such as mobility of the animals and a more restricted sample from the intestine, why results from intestinal fecal material would differ from results from fresh fecal material collected from the ground, it is surprising that they differed so often. For example, the coefficient of determination between site feces and intestinal feces was 0.646; between site feces and forage utilization it was 0.766 (Table 1).

Fewer species were identified from fecal material collected from the ground than from intestinal feces, in aggregate 23 species. Since the intestinal feces came from the rectum, there should have been little difference in the digestion processes in each case. Possibly the weathering that feces were subjected to after being deposited may have been a factor, although we collected only the fresher-appearing feces. We have in other studies where intakes were known, experienced difficulty in identifying some species in fecal matter. We are not yet certain whether this was due to alterations in diagnostic characteristics caused by digestion or whether the preparation procedures used were responsible.

Our decision to analyze intestinal feces was based on a "target of opportunity" concept. It is unlikely that wild animals would be sacrificed to obtain fecal material solely for food habits analysis. In view of the fact that in our experience the results from intestinal feces closely paralleled rumen analysis, there seems no impelling reason to make fecal examination of intestinal material, although to do so would theoretically broaden the base of the sample (by covering a larger time interval) and provide a more representative sample. Each animal might thus provide samples from two or more feeding days rather than just one.

Only in a general way do the data in Table 2 provide an index of the species consumed by antelope on the western desert valleys of Utah in summer. The vegetation in the enclosure in which the herd was confined is not entirely representative of that found elsewhere. There is more desert almond (*Prunus fasciculata*) than is found in many areas and forbs are better represented than in many adjoining areas both in number of species and amounts produced. Secondly, no collection was made in May, which tends to depress the importance of forbs in the diet since it is then that forb production is ordinarily highest. Also, bug sage (*Artemisia spinescens*), a highly preferred plant of pronghorn, is of great importance in May. Finally, the animals taken in late July and August were found in portions of the enclosure where black sage (*Artemisia nova*) was not present. This probably accounts for this species being in second place; examination of stomach contents of free-roaming pronghorn killed during the hunting season in August in areas adjacent to the station enclosure showed that black sage was over three times as important as desert almond. In part this may be due also to unavailability of desert almond in some areas from which the hunted animals came.

Our results as well as those of others which have been reported suggest that additional work must be done before the fecal analysis technique can be evaluated as a method for quantifying ruminant diets. Several factors account for this. Different plant species respond differently to the digestion process. Some species may become unidentifiable in the feces (Slater and Jones 1971). Others, though identifiable, are differently fragmented so that, if fragment counts are used as a basis for determination, the proportions of species appear different. This factor is especially important where plants of very dissimilar kinds having different epidermal characteristics are involved. For example, Owen (1975) observed marked differences in fragmentation among three grass species eaten by waterfowl.

Determining leaf area: weight ratios may solve the fragmentation problem, though there are disparities among different kinds of material from the same plant (Owen 1975) and among plants (Dunnet et al. 1973). Moreover, determinations of leaf area are not readily made. The results of these factors may require determination of conversion factors. Even so, such "equivalence factors" may have a 15-fold range (Voth and Black 1973). In addition to plant differences, the effects on the ingested material may differ among animals. In July, the amounts of *Themeda triandra* were less in the feces than in the feed of zebra and greater in the case of wildebeest and kongoni (Casebeer and Koss 1970).

Finally, the preparation of material is vitally important. The widely differing preparational procedures reported in the literature are evidence of dissatisfaction with procedures reported by others. This was our experience. It would be instructive to determine how the different preparational techniques that have been suggested affect the results obtained.

We conclude that until more is known about the effect the factors described above have on results, the determination of diets from fecal analysis must be regarded as qualitative rather than quantitative (see also Vavra et al. 1978). Moreover, it is time consuming, requires laboratory facilities, and experience. Despite these problems it may be a useful supplement to utilization estimates and other observational methods for obtaining dietary estimates of furtive and difficult-to-observe species.

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Factors Affecting Root of Stem Cuttings of Salt Desert Shrubs

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Abstract

Several variables were identified that affect rooting of stem cuttings of fourwing saltbush (*Atriplex canescens*), cuneate saltbush (*A. cuneata*), shadscale (*A. confertifolia*), spiny hopsage (*Grayia spinosa*) and greasewood (*Sarcobatus vermiculatus*). Differences in rooting were found among different individuals within the same population. Rooting varied with season of collection and with concentration of hormone application. There was an interaction between the effects of season of collection and concentration of applied hormone. Longer fourwing saltbush cuttings rooted better than shorter ones, and woody basal portions of new leaders rooted better than herbaceous tips. Sex of dioecious saltbush species was generally not an important factor in rooting success. Cuttings from greasewood plants grown in a greenhouse rooted better than field-collected cuttings.

Vegetative propagation of desert shrubs is a means of producing a number of genetically identical individuals in species whose sexually produced offspring are normally highly variable. Reduced variability of plant materials can increase experimental precision, and a large number of genetically identical individuals is necessary for varietal testing. Reproduction of desirable parent characteristics such as high seed yield would be valuable in the establishment of seed production nurseries. Vegetative propagation is also a method of producing transplants of species whose seeds do not germinate readily.

The propagation of stem cuttings of several saltbush (*Atriplex*) species and a few species from other salt desert shrub genera have been studied by Nord and Goodin (1970), Wieland et al. (1971), Ellern (1972), and Wiesner and Johnson (1977). Although these studies have provided much useful information, they have also raised further questions that need to be addressed. For example, it was not clear why hormone treatments sometimes enhanced rooting and sometimes did not. Although Nord and Goodin (1970) and Ellern (1972) observed a general trend for better rooting of saltbush (*Atriplex*) species in spring than fall, no data were available for summer and winter. Nord and Goodin (1970) noted better rooting of green stem tips than ripewood cuttings, but Ellern (1972) failed to find any difference in rooting of soft, green cuttings and young woody stems cuttings.

Certain other factors not addressed by the above cited research might also be important to the successful rooting of salt desert shrub stem cuttings. Freeman et al. (1976) found that for several dioecious species, including shadscale (*Atriplex confertifolia*), male plants were more abundant on harsher sites (more saline or xeric) and females were more abundant on the less harsh sites, suggesting that the sexes may differ in their physiological ability to survive stress. It is possible that physiological differences between sexes might also include the ability to produce adventitious roots on stem cuttings. The size of cuttings and the environmental conditions under which the donor plants are grown may also affect rooting.

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Research was conducted to shed further light on factors affecting adventitious root formation on salt desert shrub stem cuttings. The specific research objectives were to: (1) identify the optimum season to collect stem cuttings of fourwing saltbush (*Atriplex canescens*) and cuneate saltbush (*A. cuneata*); (2) determine whether or not sex of dioecious saltbush species is important to rooting of cuttings; (3) study the response of shadscale, fourwing saltbush, and spiny hopsage (*Grayia spinosa*) to various concentrations of exogenously applied indole-3-butyric acid (IBA); (4) determine whether there is an interaction of season of collection with concentration of applied hormone on rooting response of fourwing saltbush; (5) determine how size of stem cuttings and portion of stem used for cuttings affected rooting of fourwing saltbush; and (6) compare rooting of greasewood (*Sarcobatus vermiculatus*) cuttings collected from field-grown and greenhouse-grown plants.

Methods

Collection Sites

Stem cuttings of fourwing saltbush (*Atriplex canescens*), cuneate saltbush (*A. cuneata*), shadscale (*A. confertifolia*), spiny hopsage (*Grayia spinosa*), and greasewood (*Sarcobatus vermiculatus*) were collected from the vicinity of Bonanza, Uintah County, Utah. Elevations of the Bonanza collection sites range from about 1,585 m (5,200 ft) to 1,707 m (5,600 ft) and average annual precipitation ranges from 18 cm (7 inches) to 23 cm (9 inches). The salt desert shrub vegetation is grazed during the winter by sheep. For certain of the experiments, as explained below, stem cuttings of fourwing saltbush, cuneate saltbush, and shadscale were collected from Wildcat Mesa and Pete Steele Bench, two adjacent mesas in eastern Garfield County, Utah. Elevations of the Wildcat Mesa and Pete Steele Bench collection sites range from 1,707 m (5,600 ft), to 1,768 m (5,800 ft), with average annual precipitation in the 20-cm (8 inches) to 23-cm (9 inches) range. The vegetation is salt desert shrub and the primary use of the land has been for winter cattle grazing.

General Propagation Techniques

The youngest available woody stems (current year's growth in summer and previous season's growth in winter) were collected from the above field sites and placed in plastic bags. The plastic bags of cuttings were transported in styrofoam chests. Stem sections 8 cm long (except in the experiment comparing cutting length), with the lower 2 cm of leaves removed, were dipped first in water and tapped against the side of the container to remove excess water. The moistened cuttings were then dipped in talc powder containing indole-3-butyric acid (IBA) and excess powder was removed by tapping the cuttings against the container. IBA in talc powder was used because IBA has been shown to be probably the best hormone for general use due to its effectiveness in promoting root initiation of a large number of plant species and its general lack of toxicity over a wide concentration range (Hartman and Kester 1975). A concentration of 0.3% IBA was used, except in experiments testing effects of hormone concentration, because it had proved effective in preliminary experiments for promoting root initiation of several salt desert shrub species.

After hormone treatment, the cuttings were inserted one each into moistened peat pellets in plastic trays with inside dimensions of 50.8 cm × 25.4 cm × 6.4 cm. The trays of peat pellets with cuttings were kept in a translucent polyethylene enclosed chamber in a glasshouse. One side of the chamber was left open during the day to prevent excessive heat build-up. No supplemental lighting was provided.

The cuttings were sprinkled with water daily. Holes in the bottom of the trays allowed adequate drainage. A temperature of 21°C was maintained in the growth medium with thermostatically controlled electric heating pads. Air temperatures in the chamber ranged from 15°C to 29°C in winter and from 17°C to 35°C in summer. Cuttings were examined for root initiation after 30 days in the propagation chamber.

Season of Collection

Cuneate saltbush and fourwing saltbush were collected at various times from Bonanza, Utah, during the period of March 1976 through August, 1977. At each collection date 50 cuttings from each of 5 plants per species were treated as above with 0.3% IBA in talc. Percent rooting was determined after cuttings had been in the propagation chamber 30 days. The experimental design was completely randomized.

Sex of Dioecious *Atriplex*

Cuttings were collected from male and female fourwing saltbush, cuneate saltbush, and shadscale plants. Collection dates and locations are listed in Table 1. There were 5 plants per sex and 50 cuttings per plant except on the January, 1977, collection date for fourwing saltbush, when 20 male and 20 female plants were collected. After collection, cuttings were treated as stated above.

Hormone Concentration and Interaction with Season of Collection

Fifty cuttings per treatment per plant from 5 shadscale, 10 fourwing saltbush, and 4 spiny hopsage plants were collected from the vicinity of Bonanza, Utah, in March, 1977, and treated with various concentrations (0, 0.1, 0.3, 0.8, 2.0%) of IBA in talc powder. In addition, fourwing saltbush cuttings collected the previous December and the following August were also treated with the same range of IBA concentrations. There were 50 cuttings from each of 5 plants per treatment used in December and August. General propagation techniques were as stated above.

Effects of Length of Cutting and Stem Portion Used

Three lengths (6 cm, 9 cm and 12 cm) of stem cuttings were taken from a greenhouse-grown fourwing saltbush clone (a group of genetically identical plants previously propagated from stem cuttings). Three replicates of seven cuttings per length were treated by the propagation techniques stated above.

The long leaders of the above clone were cut into top, middle, and bottom portions, all 8 cm long. Five replicates of seven cuttings for each portion were treated by the general techniques stated above.

Greenhouse-Grown vs. Field-Collected Cuttings

In several preliminary trials greasewood cuttings rooted poorly if at all. To determine whether rooting of cuttings could be improved by modifying the environment under which donor plants were grown, greasewood cuttings were collected from plants in the field and in the greenhouse on two dates. There were 105 field-collected cuttings and 84 greenhouse-collected cuttings on March 24, 1976, and there were 168 field-collected cuttings and 133 greenhouse-collected cuttings on January 7, 1977. The cuttings were treated with 2.0% IBA powder (most effective concentration in preliminary experiments) and were handled by the general propagation techniques outlined above. Cutings were examined for root initiation after 40 days in the propagation chamber.

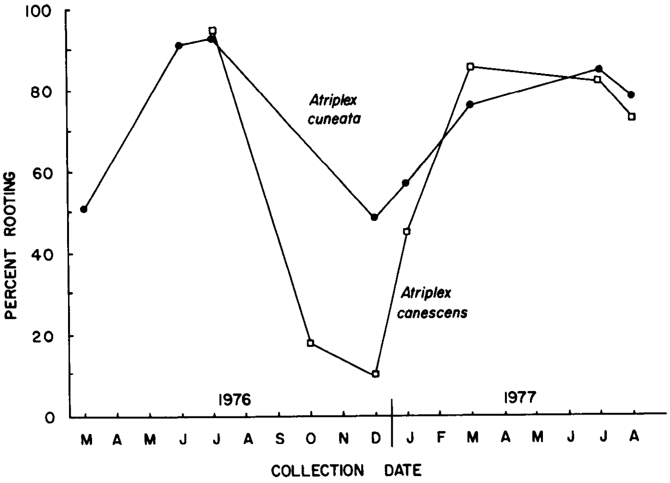

Fig. 1. *Percent rooting of stem cuttings of fourwing saltbush and cuneate saltbush collected at different times of the year. Cuttings were treated with 0.3% IBA.*

Results and Discussion

Season of Collection

Greatest rooting percentages of fourwing saltbush and cuneate saltbush occurred in spring and summer, while rooting percentages were lowest in the fall (Fig. 1). The seasonal difference in rooting is most striking with fourwing saltbush. The seasonal rooting response of these two saltbush species differs from that of big sagebrush (*Artemisia tridentata*). Big sagebrush produced peak rooting percentages in late winter, but adventitious root formation was much reduced after the onset of growth in the spring (Alvarez-Cordero 1977).

Although temperature of the rooting medium was maintained at 21°C throughout the experiment, photoperiod and greenhouse air temperatures varied seasonally. Thus it was not possible to completely separate the effects of field and greenhouse environment. However, the conditions of the experiment are typical of those conditions that will be used by people attempting to propagate the above species, and the data provide a guide for the best times to collect cuttings from the field. The optimum time for collecting cuttings from these saltbush species may be expected to vary slightly depending on elevation and latitude.

In general, highest rooting percentages of fourwing and cuneate saltbushes can be expected in the period just following the cessation of rapid spring vegetative growth before fall dormancy occurs. The period from bud swelling through rapid vegetative growth is the next most favorable for rooting of stem cuttings, followed by the late winter time during which any chilling requirement to break dormancy have probably already been met. Poorest rooting is expected during the earlier stages of dormancy in late fall. A few trials with other saltbush species (*Atriplex gardneri*, *A. confertifolia* and *A. corrugata*) suggest that they follow seasonal patterns similar to fourwing and cuneate saltbushes in their rooting responses. Other plant genera (e.g. *Artemisia*) may differ from *Atriplex* in seasonal ability of stem cuttings to initiate adventitious roots, and the optimum season for collection and rooting of their cuttings must be determined separately.

Sex of Dioecious *Atriplex*

Four separate trials with fourwing saltbush and two trials with shadscale indicate that the ability to form adventitious roots on stem cuttings is not related to the sex of these two species (Table 1). The initial trial with cuneate saltbush, collected October 23,

Table 1. Percent rooting of three saltbush (*Atriplex*) species as affected by sex of stem cuttings.

Collection date	Species	Location	Sex[1] Male	Sex[1] Female	Over-all mean	Range
10-22-76	*A. canescens*	Bonanza	18.8	19.6	19.2	0–76
1-7-77	*A. canescens*	Bonanza	28.3	29.1	28.7	0–90
3-18-77	*A. canescens*	Wildcat Mesa	6.7	12.0	9.4	0–28
3-20-77	*A. canescens*	Bonanza	36.0	31.2	33.6	0–76
10-23-76	*A. confertifolia*	Wildcat Mesa	20.7	25.4	23.1	4–54
12-4-76	*A. confertifolia*	Wildcat Mesa	58.9	60.2	59.6	30–72
10-23-76	*A. cuneata*	Pete Steele Bench	54.6*	18.6*	36.6	4–72
11-23-76	*A. cuneata*	Bonanza	12.4	7.2	9.8	0–26
3-18-77	*A. cuneata*	Wildcat Mesa	40.3*	72.0*	56.2	14–84

[1] Means of 5 plants per sex, 50 cuttings per plant treated with 0.3% IBA powder except for *A. canescens* on 1-7-77, when 20 plants per sex were collected.
* Difference between sexes significant at .05 level.

1976, from Pete Steele Bench, resulted in significantly greater rooting percentages for cuttings from male than from female plants (Table 1). However, cuttings of female plants had significantly greater rooting percentages than cuttings of male plants collected March 18, 1977, from Wildcat Mesa, only a few miles from Pete Steele Bench. A third trial with cuneate saltbush collected from Bonanza on November 22, 1976, indicated no difference in rooting between sexes.

In the course of performing the above experiments, it became evident that individual plants within a given population of a species may differ considerably in percent of cuttings initiating roots. This is demonstrated by the sometimes great range of percent rooting values (Table 1). For example, the mean rooting percentage for 40 fourwing saltbush plants collected January 7, 1977, was 28.7, but certain individual plants rooted as high as 90% and many had less than 20% of the cuttings initiate roots. Such data suggest that it is possible to select easily rooted individuals from a plant population and establish clones in a nursery to supply stem material for large scale propagation efforts. This practice has been used at Utah State University to provide a reliable source of genetically uniform plant materials for laboratory studies. No easily identifiable physical characteristics have been found yet to allow selection of easily rooted plants in the field. At present it is necessary to test the rooting ability of stems of individual plants on the propagation bench and to save the best rooting plants.

Hormone Concentration and Interaction with Season of Collection

In March, rooting percentages of spiny hopsage, shadscale, and four-wing saltbush cuttings were increased above those in the control treatments by all hormone concentrations applied (Fig. 2). Treatment with 0.3% IBA in talc powder appeared to be near optimum for adventitious root formation on shadscale. Concentrations above 0.3% reduced percent rooting of shadscale slightly, but no effects on root development, after initiation, were observed. Concentrations of IBA from 0.3% to

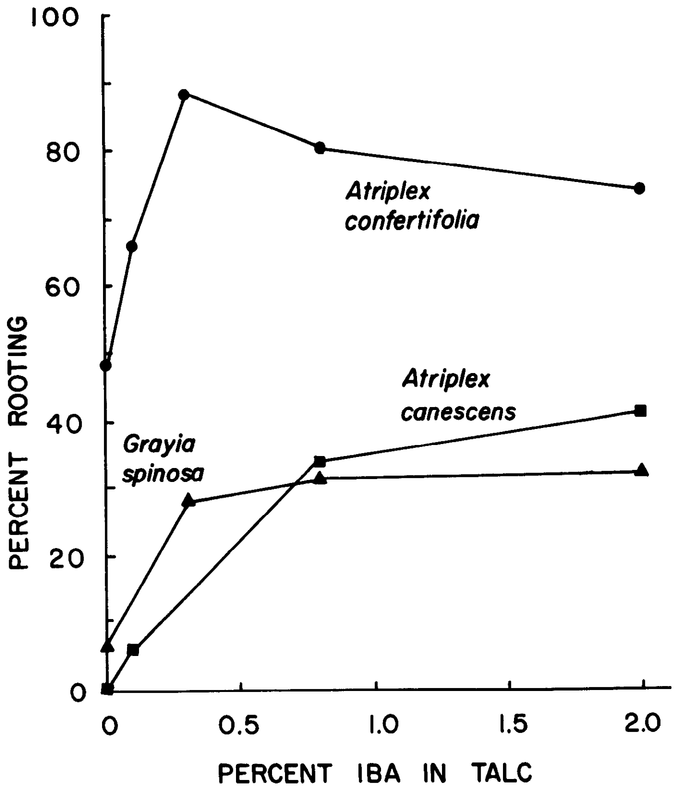

Fig. 2. *Rooting response of shadscale, fourwing saltbush, and spiny hopsage cuttings treated with various concentrations of IBA. Cuttings were collected in March, 1977.*

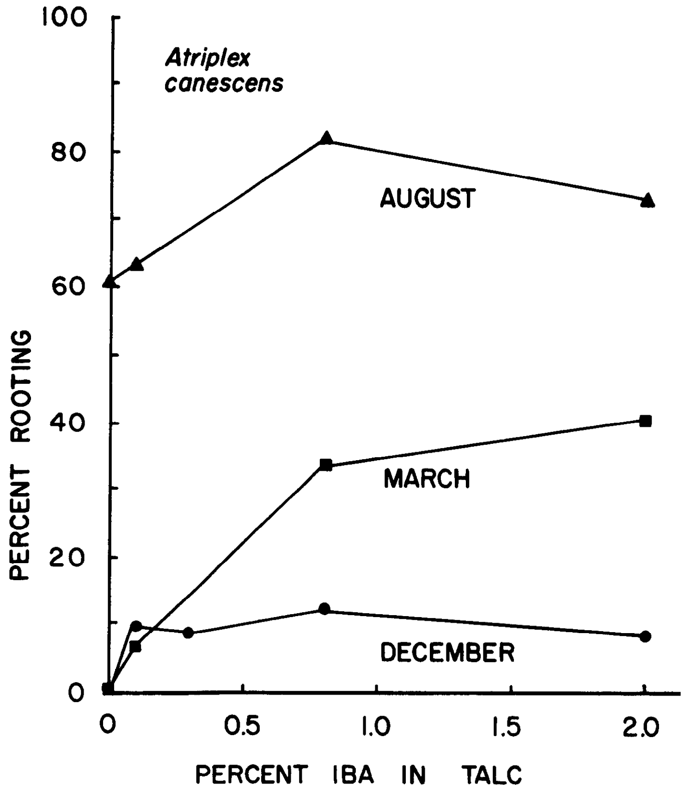

Fig. 3. *Effect of date of collection on response of fourwing saltbush cuttings to various IBA concentrations.*

Table 2. Rooting percentage of greenhouse-grown fourwing saltbush as affected by length of cutting and portion of new leader used.

Time in rooting chamber	Length of stem cutting [1,3]		
	6 cm	9 cm	12 cm
2 weeks	23.8 a	47.6 b	71.4 c
4 weeks	42.9 ab	61.9 bc	100.0 d
	Portion of leader[2,3]		
	Top	Middle	Bottom
2 weeks	2.9 w	22.9 x	40.0 y
4 weeks	22.9 x	45.7 y	60.0 z

[1] Means of 3 replications of 7 cuttings, 0.3% IBA.
[2] Means of 5 replications of 7 cuttings, 0.3% IBA.
[3] Values within experiment followed by the same letter do not differ significantly at the .05 level.

2.0% were equally effective in inducing rooting of spiny hopsage cuttings. A concentration of 2.0% IBA was only slightly more effective than a concentration of 0.8% IBA for promoting root initiation in fourwing saltbush.

The date of collection affected the rooting response of fourwing saltbush to hormone treatment (Fig. 3). Treatment of stem cuttings with IBA was required for any adventitious root initiation in December and March. The effectiveness of the hormone treatments was very limited in December but increased in March. In August, near the optimum time for collecting cuttings of fourwing saltbush, rooting exceeded 60% without hormone treatment, but treatment with 0.8% IBA still increased rooting an additional 20%. Date of collection of fourwing saltbush cuttings appears to be more important to rooting success than whether or not the cuttings are treated with IBA, because even with hormone treatments, rooting percentages in December and March were less than for untreated cuttings in August.

Effects of Length of Cutting and Stem Portion Used

Longer cuttings of fourwing saltbush rooted better than shorter cuttings (Table 2). In an effort to produce the maximum number of rooted cuttings from a given amount of stem material it may be tempting to make the cuttings short. However, this practice may not achieve the desired result. Based on the 4-week data (Table 2) and using the same amount of total stem material, fifty 12 cm long cuttings would yield 50 rooted cuttings, while one hundred 6 cm long cuttings would yield 43 rooted cuttings. The larger cuttings also produced more vigorous plants. The growth habit of the plant and environmental conditions under which the plants were grown will determine the size of cuttings (length of leaders) that can be obtained, but for best results cuttings should probably be at least 8 cm long.

The woodier bottom portions of new fourwing saltbush leaders rooted better than the more herbaceous tips (Table 5). These results differ from those of Nord and Goodin (1970); however, their use of intermittent mist may have been more favorable for rooting of herbaceous material. Basal portions of leaders must be used for shadscale and some other spinescent shrubs since no secondary shoot growth will occur from the tip portions which loose their leaves and become spines.

Greenhouse-Grown Vs. Field-Collected Cuttings

Greasewood cuttings collected on March 24, 1976, and January 7, 1977, from greenhouse-grown plants rooted 40% and 32%, respectively, while field-collected cuttings on those dates rooted only 0% and 7%, respectively. Clearly, the environmental conditions experienced by the donor plants affect rooting of cuttings. Vegetative propagation of plants, such as greasewood, that have generally proved difficult to propagate by stem cuttings may be improved when these plants are grown in a nursery situation. Yearly variations in precipitation and temperature may also produce variations in the ability of stem cuttings to root.

Differences in environment may at least partially explain the significantly (.05 level) lower percent rooting of fourwing saltbush stem cuttings collected March 18, 1977, from Wildcat Mesa in southeastern Utah than of cuttings collected March 20, 1977, from Bonanza in northeastern Utah (Table 1). The winter of 1976-77 was generally dry, but the drought was much more severe on Wildcat Mesa than at Bonanza. However, genetic differences between populations may also be a contributing factor. Both fourwing saltbush populations were in approximately the same phenological stage (i.e. just beginning spring growth) at the time cuttings were collected.

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Emergence and Survival of Honey Mesquite Seedlings on Several Soils in West Texas

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Abstract

Results from field and laboratory studies indicated that germination and emergence was adequate on soils that supported heavy densities, low densities, or no mesquite for establishment of dense populations of honey mesquite. Absence of honey mesquite or low densities of this species on soils where seeds are readily deposited by natural mechanisms could not be explained by soil chemical or physical properties that might inhibit seed germination or emergence of seedlings. In field studies, seedling emergence was not related to the density of honey mesquite presently growing on six range sites. At the end of the first growing season and at 1 year after planting, seedling survival was inversely related to density of honey mesquite. Two years after planting, seedling survival was not related to density of mesquite supported by the six soils. In this short-term study, competition with associated herbaceous vegetation overshadowed the effects of soil properties on survival of honey mesquite seedlings.

Honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) increases in abundance and invades certain range sites by means of seeds, which are transported by herbivores, wind, and water (Scifres and Brock 1970b). It is common, however, to see different soils within a pasture and under similar management supporting varying densities or no honey mesquite. The interactions of soil and other environmental factors on germination, emergence, and seedling establishment of honey mesquite are not well defined. An understanding of the factors which regulate infestation and reinfestation of rangeland by honey mesquite is needed by range managers for efficient management of this resource, and for wise planning of mesquite-control programs. This study was initiated to compare honey mesquite emergence and seedling establishment on several soils which support varying densities of this plant, and to attempt to determine if certain soil factors are inhibitory to emergence or survival of this plant.

Box (1961) reported that in the Texas Coastal Plains dense stands of running mesquite were usually associated with extremely fine-textured soils with slow permeability, poor drainage, and poorly aerated profiles (low porosity). He found that mesquite canopy cover was greatest on soils high in clay content, while mesquite density was greatest on clay loam sites. In a mesquite-buffalograss community, Box reported positive correlations of mesquite cover with litter and with soluble salts at 46 to 61 cm, and negative correlations with soil organic matter at 91 to 107 cm and with potassium at 91 to 107 cm. Mesquite cover in a chaparral-bristlegrass community was positively correlated with chlorides at 0 to 15 cm and with potassium at 46 to 61 cm. In a pricklypear-shortgrass community mesquite cover was positively correlated with phosphorus at 91 to 107 cm, and negatively correlated with soil organic matter at 46 to 61 cm.

Thomas and Young (1954) reported that in the western Edwards Plateau of Texas mesquite was more abundant on Tobosa clay soils than on four other associated soil series in their study area. The Tobosa soils occurred between the high swells and ridges (Ozona and Valera soils) and dry lake beds (Irion and Randall soils) and were moderately deep and clayey with heavier subsoils and less permeability than was found on the swells and ridges. Drainage on the Tobosa soils was slow, but water rarely stood on these soils after rains.

Welch (1968) reported that soil texture was the primary factor affecting mesquite distribution. He reported that mesquite seedlings could withstand soil moisture extremes and could survive severe drought if available moisture was reduced slowly.

Hudnall (1971) reported that whole soil soluble sodium was negatively correlated with honey mesquite canopy cover on moderately deep to deep calcareous soils on the High Plains of West Texas, while soil structure was positively correlated. He also found that $CaCO_3$ content in the A horizon and whole soil soluble Ca were significant in explaining variation in canopy cover of mesquite. For nonsaline soils, Hudnall reported that % clay in the A horizon, soluble Ca in the A horizon, and whole soil 15-bar moisture percentage explained most of the variation in honey mesquite canopy cover. Hudnall reported that honey mesquite density increased as soil maturity (judged by structural development, redistribution of $CaCO_3$, and horizonation) increased. He found high densities of mesquite on medium textured soils, while soils with low densities of mesquite or without mesquite tended to have extremes of sand or clay.

Methods

There were two aspects of this study: a laboratory study of seedling emergence and a related study of seedling emergence and survival in

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the field. Three locations studied by Hudnall (1971) were used in this study: (i) the Morgan Ranch, Andrews County, Texas; (ii) the Post-Montgomery Estate, Lynn County, Texas; and (iii) the 2S Ranch, Lynn County, Texas. These ranches were selected for study because different soil types within close proximity supported either low or high densities of honey mesquite or were void of honey mesquite plants. Soils from all three locations were used in the laboratory study. The two locations in Lynn County were used for the field study.

Laboratory Study

The objective of the laboratory study was to determine the ability of mesquite to germinate and emerge under optimum conditions in soils supporting high densities, low densities, or no mesquite in the field. Soil samples were taken from the upper 30-cm increment, which was within the upper two horizons at all sites. At each of the three locations there were three levels of mesquite density: high density, low density, and no mesquite. Three bulk samples of soil from each honey mesquite density level were collected, thoroughly mixed, and used in the laboratory study. Soil types sampled within each location are shown in Table 1.

Table 1. Properties of selected soils of West Texas (weighted for the upper 30-cm increment) that were highly correlated with emergence of honey mesquite seedlings (from Hudnall 1971).

Ranch and soil type	Mesquite density	pH	Soluble Mg^{++}	% silt	Estimated structure grade
Morgan Ranch					
Ratliff loamy fine sand	none	7.9	3.2	4.1	1.21
Portales fine sandy loam	low	7.8	1.8	10.3	2.33
Blakeney fine sandy loam	high	7.9	0.7	11.2	2.33
Post-Montgomery Ranch					
Arch clay loam	none	8.0	3.3	22.6	1.29
Veal fine sandy loam	low	7.9	0.8	10.5	1.00
Portales fine sandy loam	high	7.4	1.5	17.9	2.17
2S Ranch					
Drake sandy clay	none	7.7	11.2	9.2	1.50
Veal fine sandy loam	low	8.0	2.5	10.2	1.25
Portales clay loam	high	7.9	3.6	28.6	4.00

In the laboratory, 819 mesquite seeds that had been mechanically threshed and scarified (Flynt and Morton 1969) were planted at a depth of 1.5 cm in the mixed soil samples from each mesquite density site. The germination and emergence trial was conducted under growth lights with a 12-hr photoperiod at a mean temperature of 30.5°C (87°F). Soil water content was maintained near field capacity and the seedlings were counted 7 days after the planting date for calculating emergence percentages. Differences between mesquite density sites within a location for total numbers of seedlings emerging were determined by Chi-square analyses. Variation in emergence within the soil was not evaluated. We selected soil properties (weighted for the upper 30 cm) (independent variables) for these nine soils (from Hudnall 1971) that we felt could affect germination and emergence (dependent variable). The independent variables included: ph, % $CaCO_3$,% gypsum, % saturation, electrical conductivity mmhos/-cm), soluble Ca^{++} (meq/l), soluble Mg^{++} (meq/l), soluble K^+ (meq/l), soluble Na^+ (meq/l), % sand, % silt, % clay, % available water at ⅓ Bar, % available water at 15 Bar, inches of available water, total stress at ⅓ Bar, total stress at 15 Bar, and estimated structure grade. Hudnall (1971) has discussed the general plant relationships for each of these variables. The data were analyzed by linear stepwise multiple regression (Snedecor and Cochran 1967) to determine the relationship of emergence of honey mesquite seedlings with these soil properties. Only those soil properties that were highly correlated with honey mesquite emergence, and which were linearly independent, including pH, soluble Mg^+, % silt, and estimated structure grade (all weighted for the upper 30 cm), were used in the final analysis (Table 1).

Field Study

The field study was conducted at the 2S and the Post-Montgomery Ranches, in Lynn County, Texas. The objectives of the field study were to compare emergence in the field with that in the laboratory and to compare seedling survival of honey mesquite in soils supporting various densities of mesquite, in the presence of competition from existing vegetation. On April 13 and 14, 1972, 36 mechanically shelled and scarified mesquite seeds were planted 15-cm apart and 1.5-cm deep in each of 14 rows on 30-cm spacings within each of the three mesquite density sites (500 seeds per site) at the two locations. The native vegetation was not disturbed. The planted areas were fenced with 4-cm mesh wire and barbed wire to minimize damage to seedlings by livestock, rodents, and lagomorphs.

Seedlings were counted on May 18 and emergence percentages were calculated. On August 2, 1972, May 21, 1973, and May 14, 1974, the live seedlings were counted on each site and percent survival was recorded.

Differences between mesquite density sites within each location for total numbers of seedlings emerging and for total numbers of live seedlings on each date were determined by Chi-square analyses. Variation in seedling emergence and survival within mesquite density sites was not evaluated.

Results and Discussion

Laboratory Study

Emergence of honey mesquite seedlings was significantly higher in soils that supported either no mesquite or low densities of mesquite than in soils that supported a high density of mesquite (Table 2). Differences in emergence between soils supporting various densities of mesquite, although statistically significant ($P<0.05$), were very small and are not believed to be of biological or ecological importance. However, these data indicate that soil physical or chemical properties that inhibit germination or emergence of honey mesquite were not present in any of the nine soils studied. In years of sufficient precipitation, germination and emergence should be adequate on all of the sites studied to permit the establishment of honey mesquite.

Table 2. Percent emergence of honey mesquite in laboratory trials in soils supporting three densities of mesquite at three locations in West Texas.

Location	Soil type	Mesquite density	Percent emergence
Morgan Ranch	Ratliff loamy fine sand	none	86.4 a[1]
	Portales fine sandy loam	low	82.8 b
	Blakeney fine sandy loam	high	80.6 b
Post-Montgomery Ranch	Arch clay loam	none	80.0 ab
	Veal fine sandy loam	low	82.2 a
	Portales fine sandy loam	high	77.9 b
2S Ranch	Drake sandy clay	none	86.3 a
	Veal fine sandy loam	low	86.1 a
	Portales clay loam	high	82.2 b

[1] Values for each location followed by similar letters are not significantly different at the 5% significance level.

Stepwise multiple regression indicated that mesquite seedling emergence increased as pH and concentration of soluble Mg^{+} increased, and decreased as the proportion of silt in these nine soils increased. However, the equation[1] was not considered to be of value because of the narrow range in emergence percentages attained (Table 2) under the optimum conditions utilized in the laboratory study.

Field Study

In the field study, emergence and seedling survival varied between sites within both locations. At the Post-Montgomery Ranch, emergence was the greatest (47%) on the Portales fine sandy loam which supported a high density of mesquite, and lowest (17.4%) on the Veal fine sandy loam, which supported a low density (Table 3). The Arch clay loam, which was void of mesquite, supported an intermediate level of emergence (40.6%). At the 2S Ranch, seedling emergence was highest (45.2%) on the Drake sandy clay, which was void of mesquite, and lowest (34.2%) on the Veal fine sandy loam, which supported a low density of mesquite. Emergence was intermediate (38.8%) on the Portales clay loam, which supported a high density of mesquite (Table 3). These results did not show the same trends for emergence as were seen in the laboratory study (Table 2).

Precipitation and temperatures were adequate at both field locations for germination of honey mesquite seeds during the spring of 1972. Sites within each location were in close proximity (within 0.8-km radius), thus precipitation did not vary significantly between sites. The two ranches were also in close proximity (within 19-km radius), thus temperatures were similar between locations. Scifres and Brock (1970a) have demonstrated that honey mesquite seeds germinate most favorably at 29.5°C and reported that soil temperatures usually reach 25.6°C to 26.7°C in the upper 10 cm (4 in) around April 5 to 24 on the High Plains of Texas. Thus the requisites for honey mesquite germination would be met when spring rains occur during this period. Our field data substantiate the results from the laboratory study, that soil physical or chemical properties that inhibit germination or emergence of honey mesquite were not present in the soils studied. Emergence was adequate on all six sites for establishment of dense populations of honey mesquite. Under field conditions, the level of honey mesquite seedling emergence was not related to the density of mesquite presently supported on these six soils. Variation in percent emergence of honey mesquite seedlings between sites was not related to cover of existing vegetation, thus it is not felt that an interaction of plant cover with soil temperatures affected germination or subsequent emergence, although data on soil temperatures were not taken.

Drought conditions prevailed during most of the growing seasons of 1972, 1973, and 1974; thus conditions for mesquite seedling establishment and survival were sub-optimal at the six sites studied. These conditions provided an excellent opportunity to study the survival of honey mesquite seedlings during drought conditions. At the end of the 1972 growing season (4 months post-planting) and at the beginning of the 1973 growing season (13 months post-planting), seedling survival followed a similar trend at both locations, with survival being highest on the sites void of mesquite, intermediate on sites supporting low densities of mesquite, and lowest on sites supporting high densities of mesquite (Table 3).

[1] The regression equation, $Y = 26.40 + 7.35 X_1 + 0.52 X_2 - 0.21 X_3$, where X_1 = pH; X_2 = soluble Mg^{++}; and X_3 = % silt (all weighted for the upper 30 cm), accounted for 77% of the variation ($R = 0.88$) ($P<0.05$) in emergence of honey mesquite seedlings.

Table 3. Percent emergence and percent survival of honey mesquite seedlings in field studies on six mesquite density sites at two locations in Lynn County, Texas.

Location	Mesquite density	Percent emergence	Percent seedling survival[2] Aug., 1972	May, 1973	May 1974
Post-Montgomery Ranch	none	40.6a[1]	37 a	24 a	5 a
	low	17.4 b	29 ab	20 ab	17 b
	high	47.0 c	24 b	14 b	5 a
2S Ranch	none	45.2 a	48 a	13 a	4 a
	low	34.2 b	26 b	4 b	2 ab
	high	38.8 b	3 c	0 c	0 b

[1] Values within a column for each location followed by similar letters are not significantly different at the 5% significance level.
[2] Based on number of seedlings that emerged.

Only 3% of the mesquite seedlings survived their first summer on the Portales clay loam soil (supporting a high density of honey mesquite) at the 2S Ranch, and all of the seedlings had died on this site by the beginning of the 1973 growing season (Table 3). At 13 months post-planting, seedling survival was still significantly higher on the 2S Ranch site void of mesquite as compared to the site supporting a low density of mesquite. At 25 months post-planting the trend was similar, but the difference was not significant. This trend held for the three sites at the Post-Montgomery Ranch at 13 months post-planting, but at 25 months post-planting survival was significantly higher on the low-density mesquite site than on the other two sites. Seedling survival was equal on the Post-Montgomery Ranch site void of mesquite and that supporting a high density of mesquite at 25 months post-planting (Table 3).

We believe that the effect of existing herbaceous vegetation on the sites studied overshadowed the effects of soil properties on survival of honey mesquite seedlings during this field study; thus regression analyses to relate emergence and survival in the field with soil properties were not conducted. The site supporting a high density of mesquite at the 2S Ranch was also supporting a dense stand of tobosagrass (*Hilaria mutica*) (Table 4). We believe that the high mortality of young mesquite seedlings on this site resulted from competition with this very drought-tolerant mid-grass. Similarly, the low survival of seedlings on the site supporting high densities of mesquite on

Table 4. Cover ratings for major plants on six sites in Lynn County, Texas (from Hudnall 1971).

Plants	Honey Mesquite Density: Post Montgomery Ranch none	low	high	none	2S Ranch low	high
Aristida spp.	1[1]	3				
Bothriochloa saccaroides	1					
Bouteloua curtipendula	1	2				
Bouteloua eriopoda		2				
Bouteloua gracilis	5	2	3		3	1
Buchloe dactyloides	2	3	3	2		1
Distichlis stricta	1					
Hilaria mutica						6
Panicum obtusum	1					
Schedonnardus paniculatus				3		
Sporobolus airoides				6	1	1
Tridens pilosus	1					
Condalia obtusifolia						1
Yucca glauca		3				
Croton pottsii	1					
Atriplex canescens						1

[1] 1 = 1–5%; 2 = 6–10%; 3 = 11–20; 4 = 21–30%; 5 = 31–50%; 6 = 51–75%

the Post-Montgomery Ranch was possibly due to competition for soil moisture from the dense stand of buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*) (Table 4). Scifres and Brock (1970b) reported that honey mesquite seedling survival was greater in tobosagrass rangeland than in buffalograss rangeland at 2 months post-planting on experimental plots near Spur, Texas. Differences in precipitation between years could possibly account for this discrepancy between the two studies.

Periodic short-term and long-term droughts are common in this region of the southern Great Plains. Honey mesquite seed undoubtedly germinate readily and emerge in most soils of this region when spring rains occur. We feel that competition from exisiting herbaceous vegetation plays a major role in limiting the establishment of honey mesquite seedlings during short-term drought. However, during long-term droughts when density and vigor of herbaceous vegetation are severely reduced, mesquite seedlings may readily become established on many soils in the absence of competing vegetation. The subsequent survival of these seedlings is determined by the availability of soil water, which is a function of numerous soil properties, as well as competition from associated vegetation. Native rodents, insects, and low winter temperatures are also important factors influencing survival of mesquite seedlings (Paulsen 1950).

Conclusions

Germination and emergence of honey mesquite seedlings is probably adequate on most rangeland soils in the southern High Plains of Texas, where a seed source is present, in years of adequate spring and summer rainfall, to permit the establishment of dense populations of this plant. However, soil factors, such as available water, and ecological factors, such as competition, probably result in moisture stress and subsequent seedling mortality on many soils, which may explain why some range sites have no mesquite or low densities of mesquite.

Competition with existing herbaceous vegetation may overshadow the effects of soil properties on seedling survival during some years. Thus, during short-term droughts a good stand of grass seems to play a major role in limiting the establishment of honey mesquite seedlings.

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Control of Saltcedar by Subsurface Placement of Herbicides

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Abstract

A root plow modified for deep subsurface placement of herbicides effectively controlled saltcedar (*Tamarix ramosissima* Ledeb.). One operation, preferably in the spring, which severed the tap root 35 to 60 cm below the soil surface and simultaneously applied any of several herbicides at the same depth increased saltcedar kill by more than 100% over that of root cutting alone. Residual herbicides, including uracils, substituted ureas, 2,3,6-TBA, picloram, dicamba, and karbutilate, applied with the root plow consistently controlled saltcedar with a single treatment. Phenoxy herbicides showed initial activity against saltcedar but did not persist long enough to satisfactorily kill late sprouting, previously quiescent buds. Two arsenicals and dichlobenil were ineffective for saltcedar control.

Saltcedar (*Tamarix* spp.) originally attracted attention through its rapid invasion of channels and floodplains of streams in the southwestern United States. Robinson (1965), Case (1969) and Horton et al. (1976) reported details of this invasion, the disadvantages of saltcedar, and early organized efforts directed at its control. Long-term control required repeated chemical and mechanical treatments. Foliar sprays usually defoliated and often killed the aerial parts of saltcedar but seldom killed the root system. Bud resprouting and plant survival after chemical or mechanical control efforts were common because of poor basipetal translocation of herbicides, deep extensive root systems, and resistant root crown buds. Occasionally, resprouting was delayed for 12 to 24 months after treatment. This delayed recovery often led to false reports of good chemical control during early studies because the investigator did not allow sufficient time before making a final evaluation of saltcedar control.

Field observations supported by greenhouse studies (Quimby et al. 1977) indicate that herbicides available to the roots are readily assimilated and translocated in saltcedar. Compounds that are ineffective as foliar sprays often provide permanent control where available through the roots. However, soil and climatic conditions in the arid southwest may prevent soil-applied herbicides from reaching the root zone. In addition, saltcedar has a deep, active root system near the water table but usually has relatively few active, sorptive roots near the surface where the herbicides are likely to remain because of limited leaching. Partially buried stem segments of saltcedar following attempts at mechanical control take root readily in moist soil, increasing survival capability.

Twenty years after the first large-scale attempt to control saltcedar, the problem of getting phytotoxic amounts of herbicides into saltcedar plants had not been solved. Since natural conditions were not favorable for getting adequate amounts of herbicides into the deeper root zone, a mechanical injection method was sought. Development of a method for deep placement of herbicide, utilizing a standard root plow, was initiated in 1969. Modification of the equipment and the method have been described by Hollingsworth et al. (1973). Briefly, the operation involves cutting the tap root of saltcedar at a selected depth and simultaneously applying a herbicide with a spray boom attached to the rear edge of the plow blade. The remaining active roots in or immediately above the layer of herbicide readily absorb it.

The objective of this study was to determine the response of saltcedar, specifically *Tamarix ramosissima* Ledeb., to a variety of herbicides applied by the root plow injection method.

Materials and Methods

Herbicides were applied with either a 1.22 or 2.44-m wide root plow. All treatments were duplicated and the data were subjected to analyses of variance for a randomized complete block design. Means were compared by Duncan's multiple range test at the 95% level of probability.

The first experiment was established on the Cimarron River floodplain near Ashland, Kansas, on June 19, 1969. The area consisted of mildly saline, subirrigated, moderately well-drained sandy loam soil. The water table was 72 to 96 cm deep and regrowth saltcedar from established root crowns averaged 3 m tall. The average annual rainfall is about 56 cm and rainfall between June 19 and October 22 was 42

Table 1. Percentage saltcedar killed 28 months after application of herbicides at an average depth of 50 cm by the root-plow method in June 1969, Cimarron River floodplain near Ashland, Kansas.

Treatment		Control (% kill)	
Herbicide	Rate (kg/ha)	Root-plowed swath[1]	Uncut strip between swaths
Monuron	5.6	100 a	50
Diuron	5.6	98 a	80
Picloram: 2,4,5-T (1:4)	4.5	95 a	50
Dicamba	9	92 a	15
2, 4-D Alk	9	88 a	0
None (root-plowed check)	–	54 b	0

[1] Based on count of 300 plants per plot in duplicate per treatment; means followed by a letter in common are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

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cm. The 2.44-m wide plow blade was operated at a depth of 50 cm in 0.2 ha plots and the herbicides were applied in 900 liters/ha of water. The percentage of saltcedar kill was determined 28 months after treatment by counting 300 plants per plot within the plow swaths and comparing live and dead plants. In addition, all plants were counted in several uncut narrow strips between plow swaths and the percentage plant kill determined. Statistical analysis was not performed on the data from uncut strips.

A second experiment was established on the Rio Grande floodplain near Bernardo, New Mexico, on July 30, 1970. The sandy clay loam was highly saline and poorly drained. Regrowth from the crowns of saltcedar that had been burned or mowed periodically for several years ranged from 1.5 to 2 m tall. The water table was 48 to 72 cm deep and the 1.22-m wide plow blade was operated 30 to 40 cm deep. The herbicides were applied in 900 liters/ha of water to 0.01-ha plots. An estimate of the percentage of treated plants showing regrowth was made periodically. Two of these observations, 2 and 12 months after treatment, are shown in Table 2. Five years after treatment, the surviving plants in each plot were counted and compared with the total number of plants at the time of treatment (Table 2).

Table 2. Saltcedar regrowth within 1 year and percentage plants killed 5 years after application of herbicides at an average depth of 35 cm by the root-plow method in July 1970, Rio Grande floodplain, Bernardo, New Mexico.

Treatment		Regrowth[1] (%)		
Herbicide	Rate (kg/ha)	2 months	12 months	Control[2] (% kill) after 5 years
Bromacil	11	75	8	99 a
Dichlobenil + picloram	5 + 5	25	4	98 a
Terbacil	11	75	8	98 a
Dichlobenil + dicamba	5 + 5	15	3	97 a
Monuron	11	85	18	95a
2,3,6-TBA	11	30	15	91 a
Picloram + dicamba	5 + 5	20	4	90 a
Dicamba	11	45	20	90 a
Picloram + amitrole	5 + 5	45	5	89 a
Dichlobenil	11	40	38	85 ab
Silvex PGBE	11	45	25	83 ab
2,4-D Alk + 2,4-D PGBE	5 + 5	25	25	80 ab
Silvex K-salt	11	40	28	79 ab
None				
Root-plowed check	–	70	47	65 b
Unplowed check	–	100	100	0 c

[1] Two visual estimates for each treatment, hence no statistical analysis.
[2] Based on count of total plants per plot in duplicate plots per treatment; means followed by a letter in common are not significantly different a the 0.05 level of probability according to Duncan's multiple range test.

A third experiment was established on the Rio Grande floodplain near Bernardo, New Mexico, on April 8, 1971. Soil characteristics, saltcedar regrowth, plot size, and treatment procedures were similar to those described in the second experiment. The 1.22-m wide plow blade was used to apply the herbicides. The percentage plant kill was determined at 6 months and 4.5 years after treatment by comparing surviving plants with the total number of plants per plot at the time of herbicide application.

A fourth experiment was established on the New Mexico Game and Fish Commission refuge at Bernardo, New Mexico, on August 4, 1971. The soil was highly saline, subirrigated, sandy clay loam. The well-established, dense, 10- to 15-year-old saltcedar plants had been periodically mowed or burned, and regrowth since mowing 5 months earlier was 60 to 90 cm tall. The saltcedar density had reduced the native grass stand to 10% or less throughout the experimental area. The water table was 72 to 84 cm deep and the 2.44-m wide plow blade was operated at a 60 cm depth. The herbicides were applied in 400 liters/ha of water to 0.16-ha plots. The percent saltcedar control was determined 4 years after treatment by recording the number of surviving plants out of 600 plants examined per plot (Table 4). Reinfestation by two of the more prominent native grasses, desert saltgrass [*distichlis stricta* (Torr.) Rydg.] and alkali sacaton [*Sporobolus airoides* (Torr.)], was also noted. The extent of each grass species was estimated by two individuals and their results were averaged to give the percent infestation.

Results

The first two experiments with the root-plow injection technique required minor adjustments in the equipment and operation. It was necessary to adjust the blade angle or pitch to keep the plow in the soil with a minimum of power drag. The spray system provided uniform herbicide application without nozzle clogging. However, when the saltcedar plants were too large to pass easily through the throat of the plow, occasional stops were necesary to remove the obstruction. Most trouble-some for the larger plow (2.44-m wide blade) were plants more than 3 m tall and for the smaller plow (1.22-m wide blade) those more than 2 m tall. This difficulty was resolved by crushing, burning, or otherwise reducing the size of large saltcedar prior to plowing.

A second operational problem not anticipated was the need for adjacent plow swaths to join or slightly overlap. If the taproot of saltcedar was not severed the plant often survived. Such plants were usually located in a narrow unplowed strip between plow swaths. Survival of uncut plants was further dependant upon the type of herbicide used in adjacent plow swaths. Herbicides with short residual activity, such as the phenoxy compounds, usually did not control uncut plants. Substituted ureas or the uracils provided longer residual activity and often killed plants in the unplowed strip even though the taproot had not been severed.

Several herbicides killed 35 to 45% more of the saltcedar plants than did root plowing alone (Table 1). The percentage of plants killed was lower in the uncut strips than in the adjacent root plowed swaths, reflecting an increase in survival ability of those plants whose roots were not severed. Plants in uncut strips adjacent to plow swaths treated with 2,4-D [(2,4-dichlorophen-oxy) acetic acid] and dicamba (3,6-dichloro-o-anisic acid) were least affected; but 50 and 80%, respectively, of uncut plants adjacent to monuron [3-*p*-chlorophenyl-1,1-dimethylurea]- and diuron [3-(3,4-dichlorophenyl)-1,1-dimethylurea]-treated swaths were dead after more than 2 years. Additional obser-vation revealed no apparent increase in saltcedar infestation in these plots 7 years after treatment.

Saltcedar responded dramatically to severing of the root system in July when the plants were apparently under moisture stress. After root plowing, leaves withered and bleached severely within 24 hours. Defoliation was complete within a few days. Despite this dramatic initial response, 35% of the plants survived in the root-plowed plots which were not treated with herbicide (Table 2). Two months after treatment, regrowth was extensive in several plots. After the plants had experienced a winter and the herbicides had apparently been more fully assimilated, the level of regrowth was reduced in many treat-ments. After 5 years, one application of each herbicide treat-ment had killed 80% or more of the plants. Nine treatments, which killed 89% or more plants, were significantly better (0.05% level) than root plowing alone (Table 2).

The third experiment compared the activity of representative compounds from nine classes of herbicides: substituted ureas, picolinic acid, uracil, anisic acid, benzonitrile, benzoic acid, phenoxyacetic acid, carbamate, and arsenical. Several her-bicides were evaluated in combination with other herbicides.

When evaluated 4.5 years after application, nine treatments had killed 85 to 100% of the saltcedar, a significantly higher percentage kill than that for the other 14 treatments (Table 3). Diuron, picloram (4-amino-3,5,6-trichloropicolinic acid), bromacil (5-bromo-3-*sec*-butyl-6-methyluracil), and dicamba applied at 9 kg/ha killed 100, 99, 98, and 98% respectively of the saltcedar. Karbutilate (*tert*-butylcarbamic acid ester with 3-(*m*-hydroxyphenyl)-1,1-dimethylurea], a carbamate with urea linkage, also provided good control (90% kill). Combining the various phenoxy compounds with picloram did not increase control over that resulting from picloram alone, and dicamba with dichlobenil (2,6-dichlorobenzonitrile) was less effective than dicamba alone. All herbicide treatments except the propyleneglycol butylether ester of silvex [2-(2,4,5-trichlorophenoxy) propionic acid], dichlobenil alone, cacodylic acid (hydroxydimethylarsine oxide), and MAA (methanearsonic acid) were significantly more effective than root plowing alone (Table 3).

Table 3. Control of saltcedar 0.5 and 4.5 years after application of herbicides at an average depth of 35 cm by the root plow method in April 1971, Rio Grande floodplain, Bernardo, New Mexico.

Treatment		Control[1] (% kill) after	
Herbicide	Rate (kg/ha)	0.5 year	4.5 years
Diuron	9	45 fg	100 a
Picloram	9	100 a	99 a
Bromacil	9	75 b	98 ab
Picloram:2,4-D (1:2)	9	98 a	98 ab
Dicamba	9	90 a	95 ab
Picloram:2,4,5-T (1:1)	9	90 a	95 ab
Picloram:2,4,5-T (1:4)	9	90 a	95 ab
Karbutilate	17	65 bcd	90 abc
Dichlobenil + dicamba	5 + 5	75 b	85 abcd
2,4-D DMA	11	60 cde	80 bcde
Silvex BE	11	45 fg	80 bcde
2,3,6-TBA	9	70 bc	80 bcde
2,4-D Alk + 2,4-D BE	5 + 5	60 cde	75 cde
Dicamba:2,4-D	11	60 cde	75 cde
2,4-D BE	11	50 efg	75 cde
Silvex K-salt	11	55 def	70 def
2,4-D Alk	11	60 cde	70 def
2,4-D:2,4,5-T	11	40 gh	65 efg
Silvex PGBE	11	25 i	55 fgh
Dichlobenil	11	10 j	50 ghi
None (root-plowed check)	–	30 hi	40 hi
Cacodylic acid	9	0 i	40 hi
MAA	9	5 j	35 i

[1] Based on count of total plants per plot in duplicate plots per treatment; means followed by a letter in common are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

The herbicides used in the final experiment were selected primarily because of their residual weed-control properties and satisfactory performance in earlier experiments. Dichlobenil is an exception in that it controlled saltcedar satisfactorily in the second experiment but not in the third.

Picloram was as effective alone as when it was used at 6 kg/ha in combination with dichlobenil (Table 4). Three kg/ha of picloram combined with dichlobenil provided significantly less saltcedar kill than any of the other herbicide treatments. All other treatments, with herbicides, killed at least 85% of the plants which was significantly more than the 40% kill by root plowing alone.

Release from the dense competition of saltcedar following herbicide application permitted recovery of suppressed grasses in those instances where they were not adversely affected by the herbicides (Table 4). Bromacil and diuron were most damaging

Table 4. Control of saltcedar and the response of two native grasses 4 years after application of herbicides at an average depth of 60 cm by the root-plow method in August 1971, Rio Grande floodplain, Bernardo, New Mexico.

Treatment		Saltcedar		Percent infestation of indigenous grasses	
Herbicide	Rate (kg/ha)	Surviving plants	Control[1] (% kill)	Desert saltgrass	Alkali sacaton
Bromacil	7	4	99a	20	10
Diuron	6	2	99 ab	60	0
Diuron + picloram	3 + 3	12	98 ab	70	20
Picloram	7	21	97 ab	70	30
Dichlobenil + picloram	6 + 6	25	96 ab	70	20
Dichlobenil + dicamba	6 + 6	30	95 ab	80	20
Dicamba + picloram	6 + 6	60	90 bc	90	0
Dicamba	7	90	85 c	80	15
Dichlobenil + picloram	6 + 3	180	70 d	80	10
None					
Root-plowed check	–	363	40 e	50	0
Unplowed check	–	600	0 f	10	0

[1] Based on a count of 600 plants per plot in duplicate plots per treatment; means followed by a letter in common are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.

to desert saltgrass, the more prominent of the two species. The other treatments permitted a large increase in desert saltgrass infestation over that of the unplowed check. The presence of alkali sacaton was too variable within and between plots to establish a clear pattern of response to the various herbicides.

Discussion

This study shows that a single treatment combining root plowing and subsurface application of certain herbicides will satisfactorily control saltcedar. The percentage kill is higher than for root cutting alone and a larger, more permanent control is possible than with one application of a herbicide alone.

Picloram and dicamba were the most effective herbicides for control of saltcedar and were less damaging to the native grasses. The flush of regrowth and subsequent increase in kill from 2 to 12 months (Table 2) indicates a need to wait at least 1 year after treatment before making a final determination of saltcedar response.

Use of root cutting concurrent with subsurface herbicide application may be the most effective and economical method of treatment for saltcedar on sites where the equipment can be operated. Cutting, burning, or crushing large saltcedar a few weeks before root plowing facilitates the use of this method. The percentage kill of saltcedar from the combined treatment, using various herbicides, was more than double that from root plowing alone. In the earlier experiments, the advantage of the herbicide plus root plow treatment was less apparent because of the presence of surviving plants (in strips between plow swaths) whose root escaped cutting.

Many herbicides can kill saltcedar when they enter through the root system, but the root system is the plant part best protected by nature from exposure to herbicides. Use of the root plow for subsurface application not only places the herbicide close to the roots, but it also cuts off the lower roots and, thereby, all access to moisture and nutrients except by the remaining roots near the herbicide-treated soil.

Variation between treatments in the amount of saltcedar regrowth at 2 months (Table 2) and of control at 0.5 year (Table 3) suggests a difference in herbicide absorption and translocation and/or differential susceptibility to herbicides. Prolific shoot formation from previously quiescent buds is often apparent a few weeks after treatment of saltcedar with a herbicide. Perhaps the buds must sprout and become active before the herbicide can be absorbed. Compounds that provide only a short-term residual action may dissipate before all viable buds become active. The more persistant herbicides such as bromacil, terbacil (3-*tert*-butyl-5-chloro-6-methyluracil), diuron, and monuron [3-(*p*-chlorophenyl)-1, 1-dimethylurea] provide less early control and equal or better final control than the other treatments (Tables 2 and 3). This indicates that herbicides with longer residual action may be a better selection for overcoming herbicides would also be an advantage where time may be required for the root system to grow into contact with the herbicide or the herbicide to diffuse into the root zone. Such a time requirement may have been responsible for the delayed kill of saltcedar plants in the uncut strips between plow swaths.

Use of the root-plow for subsurface application of herbicides offers the following advantages over traditional means of saltcedar control: (1) a single treatment any time during the growing season places the herbicide so that its activity is least affected by rainfall, wind, or temperature change. This type of application is relatively safe with regard to drift or to direct contact with wildlife. (2) The method can be used where saltcedar removal would be most beneficial, i.e., on flat land for row crops or flat or rolling ground for forage crops and grazing. (3) When properly done, the mechanical operation does not excessively disturb the sod or soil surface. Established grasses survive and quickly benefit from the release from saltcedar competition. Livestock grazing and mowing can continue after treatment. (4) The application cost, though initially higher than that for some traditional treatments, is lower than that for the separate mechanical and chemical operations, repeated over several years, that would be necessary for equal control.

Development of the root plow method of herbicide injection covered a period of 3 years. Unfortunately, the federal research station at Los Lunas, New Mexico, was terminated before early screening experiments could be completed and optimum herbicide rates determined for inclusion in repeated experiments. The results of four experiments have been presented because the preliminary evidence indicates that the root plow method of herbicide injection for saltcedar control has merit and deserves further refinement.

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Response of Native Grassland Legumes to Water and Nitrogen Treatments

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Abstract

The response of native shortgrass prairie legumes to water and nitrogen additions was evaluated utilizing a replicated factorial design of two water and two nitrogen treatments. Responses measured were densities and aboveground biomass by species. Water treatment greatly increased both density and biomass of legumes, presumably because of more favorable conditions for nitrogen fixation and increased competitive advantage under nitrogen deficient conditions.

The availability of nitrogen, more than any other mineral element, is a critical determinant of both the structure and productivity of grassland plant communities (Date 1973). Additionally, mineral nitrogen supplies to the plant community largely determine the value of the biomass produced as forage for consumers. In native grasslands nitrogen-fixing plants are presumed to occupy an important position in nitrogen cycling although for most grasslands very little is known about the ecology or functional significance of native legumes (Becker and Crockett 1976). This is particularly true of the semiarid grasslands of the Great Plains of North America. The majority of the information available concerning the ecology of legumes in these grasslands is available as an incidental portion of the data collected on the dominant grassland plants (Albertson 1937; Hanson and Whitman 1938; Dyksterhuis 1946; Brown 1971; Hyder et al. 1975).

As a first step in understanding the functional role of legumes in a shortgrass prairie, we provide basic phytosociological data for legumes under ambient environmental conditions and results from experimental manipulation of soil water and mineral nitrogen availability.

Methods

Site Description

The Pawnee Site[1] is located in northeastern Colorado approximately 61 km northeast of Fort Collins. The climate of the region is temperate semiarid receiving approximately 310 mm of annual precipitation. The eight experimental plots were located within an exclosure on an Ascalon sandy loam soil.

The vegetation of the area is characterized by the predominance of the shortgrass blue grama [*Bouteloua gracilis* (H.B.K.) Lag.].[2] Important associated species include fringed sagewort (*Artemisia frigida* Willd.) and plains pricklypear (*Opuntia polyacantha* Haw.).

Experimental Design

The experiment was initiated in 1970 utilizing a replicated factorial design of two water and two nitrogen treatments. Each of the two replicates included four 1-ha plots consisting of a control, water, nitrogen, and water plus nitrogen treatments.

The nitrogen treatment criterion was to maintain a difference of at least 50 kg ha^{-1} of mineral nitrogen ($NH_4^+ + NO_3^-$) between the control and the nitrogen treated plots. This was accomplished by spring applications of ammonium nitrate fertilizer as necessary based upon soil nitrogen analyses. The water treatment consisted of maintaining soil matric potential at a depth of 10 cm, above −.08 bars during the May to September growing season. Matric potential was maintained within the treatment range by nightly applications of water with a solid set sprinkler system and monitored by ceramic tensiometers. Although the experiment was begun in 1970, the water treatment criterion was not satisfactorily met until 1971.

Legume Biomass and Density

Aboveground biomass (live + attached dead) was collected on eleven dates in 1970, three dates in 1971, nine dates in 1972, and six dates in both 1973 and 1974. In 1970 ten 0.25-m^2 quadrats were harvested at ground level for each treatment on each date. During the remaining years twelve 0.50-m^2 quadrats were harvested for each treatment on each sample date.

Numbers of individuals of each species occurring within one hundred 0.25-m^2 quadrats per treatment were recorded on approximately July 1 in each year from 1971 through 1974.

Results

Water is clearly an important factor limiting legume populations in shortgrass prairies (Fig. 1). Initial densities of legumes ranged around 1 m^{-2} for all three treatments and the control (Table 1). Densities remained less than 1 m^{-2} for the nitrogen treatment and the control throughout the 4 years of study. Legume density on the water plus nitrogen treatment increased dramatically during the second year of treatment presumably as a result of the favorable growing conditions produced by this treatment. The decreases in density observed during the last 2 years on the water plus nitrogen treatment were very likely the result of increased competition from species better able to utilize the elevated levels of water and mineral nitrogen. The poor competitive ability of legumes in pastures fertilized with mineral nitrogen is well established (Templeton 1976). Density of legumes on the water treatment increased in each year of the study and in 1974 was approximately 30 times greater than the control.

A total of seven species of legumes were encountered throughout the study period; the largest number of these was

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[1] The field research facility of the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, located on the Central Plains Experimental Range which is administered by the USDA Science and Education Administration, Agricultural Research.

[2] Nomenclature follows Harrington (1954).

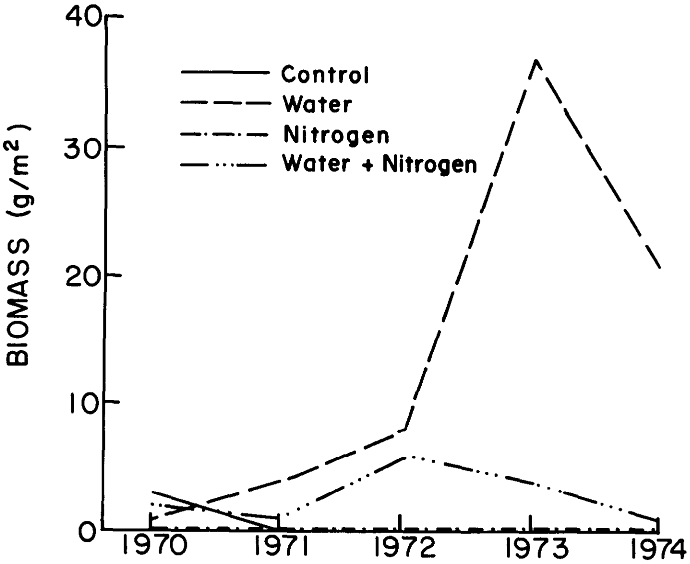

Fig. 1. *Interseasonal changes in seasonal-mean biomass of legumes for four water and nitrogen treatments in a shortgrass prairie in northcentral Colorado.*

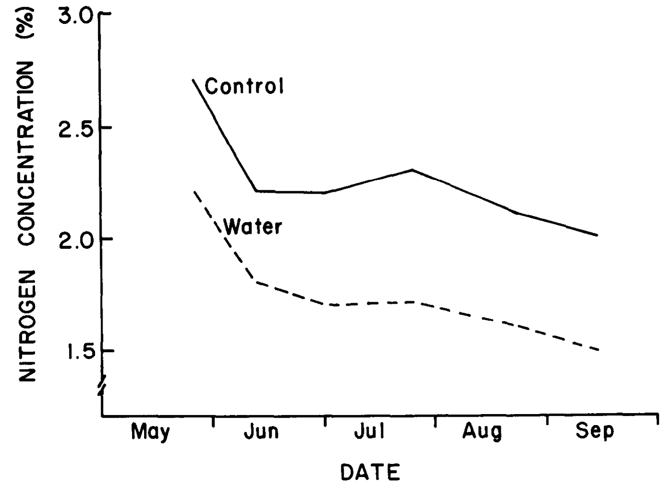

Fig. 2. *Three-year average nitrogen concentration (% ash-free) for* Bouteloua gracilis, Sphaeralcea coccinea *(Pursh) Rydb. and* Carex eleocharis *Bailey from the control and water treatment in a shortgrass prairie in northcentral Colorado.*

found on the water treatment (Table 1). Only two species, *Psoralea tenuiflora* Pursh and *Sophora sericea* Nutt., were found consistently on the control plots. Despite the large increases in the populations of legumes recorded for the water treatments, it is clear that they comprise a small proportion of shortgrass prairie vegetation. Under control conditions legumes comprised 1% or less of the total plant density throughout the study period.

Analysis of variance of seasonal-mean biomass of legumes resulted in significant treatment ($P<0.001$) and year ($P<0.05$) and a significant treatment × year interaction ($P<0.001$). The source of these significant differences can be largely explained by the biomass changes resulting from water treatment (Fig. 1). Biomass of legumes on the water treatment increased through 1973 with the largest increase occurring between 1972 and 1973. The decrease in average plant size (biomass/density) in 1974 was probably the result of difficulty in continuously maintaining soil matric potential between 0 and −0.8 bars. Biomass of legumes on the control and nitrogen treatment was greater than 1 g m^{-2} only in 1970.

Discussion

The success of legumes under conditions of increased water availability was not an unexpected result and the explanation for it certainly must be related to the physiology of nitrogen fixation as well as the competitive advantage of legumes under nitrogen deficient conditions. Vincent (1965) reviewed the subject of microenvironmental effects on nitrogen fixation by legumes and reported inhibition of nodule formation and nitrogen fixation by combined nitrogen and stimulation of bacterial populations, nodule formation, and nodule functioning with increased soil water availability. To illustrate the reduced nitrogen availability under conditions of the water treatment, Figure 2 compares the nitrogen contents of three important nonleguminous species from the control and the water treatment. Since increases in primary production of these grasslands as a result of small additions of mineral nitrogen have been reported (Hyder et al. 1975), data from the control can be interpreted as minimum estimates of adequate nitrogen availability. It is clear from these data that legumes with their ability to fix atmospheric nitrogen should have a competitive advantage over species that must rely solely on soil nitrogen.

Table 1. Density of legumes (no. m^{-2} ± 1 SE) for a shortgrass prairie subjected to water and nitrogen treatments.

	Control				Water				Nitrogen				Water + nitrogen			
Species[1]	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974	1971	1972	1973	1974
ASGR	—	—	—	—	—	—	.32±.28	—	—	—	—	—	—	—	—	
ASMI	—	—	—	—	—	—	.20±.16	.16±.16	—	—	—	—	—	—	—	—
ASMO	—	—	.04±.04	—	.36	.32±.12	.20±.10	.12±.09	—	—	—	—	—	.28±.13	.08±.06	.08±.08
LUPU	—	—	—	—	.08	—	.04±.04	—	—	—	—	—	—	—	—	—
OXLA	—	—	—	—	—	.36±.12	—	—	—	—	—	—	—	.12±.07	—	—
PSTE	.20	.44±.17	.16±.11	.06±.08	.56	.72±.27	1.28±.37	1.12±.27	.52	.44±.29	.04±.04	—	.32	.88±.27	.08±.06	.16±.10
SOSE	.12	.44±.17	—	.08±.06	.28	1.32±.39	1.88±.55	2.80±.72	.04	.28±.29	.04±.04	.04±.04	.12	1.36±.48	1.08±.33	.72±.23
Total	.32	.88	.20	.14	1.28	2.72	3.92	4.20	.54	.72	.08	.04	.42	2.64	1.24	.96
Percent of total community density	1	1	<1	<1	1	3	6	4	1	1	<1	<1	<1	4	3	3

[1] ASGR = *Astragalus gracilis* Nutt., ASMI = *Astragalus missouriensis* Nutt., ASMO = *Astragalus mollissimus* Torr., LUPU = *Lupinus pusillus* Pursh, OXLA = *Oxytropis lambertii* Pursh, PSTE = *Psoralea tenuiflora* Pursh, SOSE = *Sophora sericea* Nutt.

The clear sensitivity of nitrogen fixation to water availability (Vincent 1965) raises serious questions about the potential contribution of legumes to the nitrogen economy of semiarid grasslands. Reuss (1971) in a preliminary investigation of the role of symbiotic nitrogen fixation in a shortgrass prairie concluded legumes probably contributed less than 1 kg ha^{-1} to the annual nitrogen balance. Although this is a very small amount of nitrogen, it did account for 20% of the total annual inputs. Woodmansee (1978) presented a more pessimistic view of the potential inputs of nitrogen from symbiotic fixation for six semiarid and arid grasslands, indicating an average of less than 0.5 kg ha^{-1} $year^{-1}$ for each site. For a shortgrass prairie this amounted to 7% of his estimate of total annual input. Reuss (1971) attributed the small contribution of nitrogen by symbiotic fixation to small populations of legumes and the short duration of conditions favorable for nitrogen fixation.

Additions of water to the shortgrass prairie changed these circumstances significantly. Increased availability of soil water for the entire growing season dramatically increased the size of the legume population and presumably also resulted in much more favorable conditions for nitrogen fixation. Utilizing Reuss's (1971) figures for fixation rates of various species, calculated nitrogen fixation for the water treatment ranged from less than 1 kg ha^{-1} $year^{-1}$ in the 1970 to 18 kg ha^{-1} $year^{-1}$ in 1973.

The above estimates assume that legumes are the only N-fixing species in the community although there is some evidence that other species may fix nitrogen symbiotically, particularly fringed sagewort and plains pricklypear (Porter 1969). If we assume that legumes are the most active nitrogen-fixers in the shortgrass prairie, the large increase as a result of supplemental watering suggests a balance between nitrogen fixation and soil water availability. Masefield (1958) found that wet soil conditions resulted in high nodulation of legumes. Although our data are far from conclusive evidence, the general trends lead us to the conclusion that the legumes on the water treatment will continue to increase until enough nitrogen is being fixed so that the population of legumes will be limited by competition from the remainder of the community. An analogous situation has been reported in pasture mixtures of grasses and legumes (Blaser and Brody 1950; Templeton 1976). Increased nitrogen availability either by fertilization or nitrogen fixation intensifies competition between grasses and legumes.

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Response of Blue-winged Teal to Range Management on Waterfowl Production Areas in Southeastern South Dakota

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Abstract

The blue-winged teal (*Anas discors*) was the predominant upland-nesting waterfowl species in Waterfowl Production Areas (WPA's) in southeastern South Dakota. In native plant communities, factors that resulted in high nest density and success were excellent range condition (high proportion of climax vegetational and matted residual vegetation. In tame plant communities, smooth bromegrass (*Bromus inermis*) cover in which residual vegetation formed a matted mulch had high nest densities and nest success.

Many prime wetland areas that have been acquired in the prairie pothole region of the United States by the Fish and Wildlife Service are known as Waterfowl Production Areas and are managed as breeding habitat for waterfowl. Habitat conditions for nesting waterfowl are improved by the maintenance of certain vegetative characteristics of native and tame plant communities and by controlling the state of plant succession.

Conflicting opinions on proper management of grassland nesting cover for individual waterfowl species probably results from differences in habitats at different geographical locations and the proportion of different duck species on a study site. Nesting habitat in Iowa that had Kentucky bluegrass (*Poa pratensis*) as the dominant cover type and that was grazed lightly to moderately was more productive of blue-winged teal than was ungrazed habitat. Overgrazing was detrimental to teal production (Bennett 1938; Glover 1956; Burgess et al. 1965). Where the surface-feeding duck population included nearly equal proportions of mallards, gadwalls, pintails, and blue-winged teal in North Dakota, overall duck production was reduced considerably by grazing (Kirsh 1969). The potential production of upland nesting waterfowl will increase as our understanding of the relationships between plant and animal communities increases. Our study was designed to determine plant community types and vegetational characteristics present on the WPA's that provide habitat for upland-nesting waterfowl. Field work was conducted in spring and summer of 1974, while the senior author was a student employee at the Lake Andes National Wildlife Refuge, Lake Andes, South Dakota.

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Study Area and Methods

We studied 29 WPA's, in the prairie pothole region of southeastern South Dakota, that were acquired between 1963-1973. Twenty-two were in the Lake Andes Wetland Management District and 7 were in the Madison Wetland Management District. All were located in three vegetative zones recognized by Johnson and Nichols (1970) in eastern South Dakota: Zone 1—original tall grass prairie, Zone 2—tall-mixed grass transition area, and Zone 3—mixed grass prairie (Fig. 1).

In general, annual precipitation decreases from east to west and is 56 cm in the tall prairie, 51 cm in tall-mixed grass transition area, and 43 cm in the mixed grass praire. Precipitation was below normal in eastern South Dakota during January-July 1975 by 6.6 cm in the northern half of the study area and 14.7 cm in the southern half.

The study WPA's were selected to provide a representative sample of the upland plant communities. The presence of Type IV or Type V wetland semipermanent-to-permanent water conditions (Stewart and Kantrud 1971) was a requirement for site selection.

Upland plant communities were classified as: (1) native prairie or (2) tame grass or legume seedings (seedings by mechanical techniques). Approximately 450 ha of native plant communities and 515 ha of seeded plant communities were selected for nest searching. Some of the tame grass and legume seedings were present at the time of acquisition and others were planted later, mainly during the period 1970-73. All tame plant communities were left idle after acquisition or planting.

In general, the tracts of native prairie have degenerated because of poor management before acquisition or because they were left in a resting state for as many as 8 years after acquisition. Consequently, periodic manipulation was necessary. Burning is recognized as an effective management tool to maintain prairie grasslands, but the

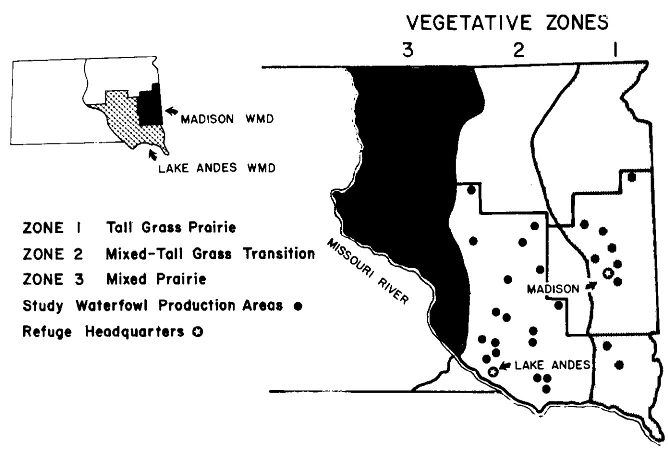

Fig. 1. *Vegetational zones within the Lake Andes and Madison Wetland Management Districts in southeastern South Dakota and the Waterfowl Production Areas (WPA's) of the study area.*

Table 1. Total ducks nests, nest success, and nest density in native *vs.* tame plant communities in southeastern South Dakota, 1974.

Species	All nests				Native[3]	Tame
	Number	Nonactive nests[1]	Percent composition[2]	Number successful	Number nests	Number nests
Blue-winged teal	210	13	79.8	95 (43)[4]	104 (49)[4]	106 (36)[4]
Mallard	23	3	8.7	8 (37)	4 (67)	19 (30)
Gadwall	23	2	8.7	13 (57)	3 (100)	20 (51)
Pintail	4	0	1.6	2 (42)	3 (100)	3 (22)
Shoveler	3	0	1.2	0 (0)	1 (44)	0 (0)
Total	263	18	100	118 (43)	115 (50)	148 (36)
Nest density					25.6/km²	28.7/km²

[1] Nests with no chance for success (crushed by search vehicle, search caused desertions, or fate unknown) are not included in success ratios or percent composition.
[2] Does not include the nonactive nests.
[3] Native=47% of area searched; Tame=53% of area searched.
[2] Nest success calculated by Mayfield (1961) method.

combination of limited manpower and wide distribution of WPA's reduced the applicability of this technique in this area where many units were no larger than 32 ha. To reduce the thick mat of residual vegetation, some native tracts were hayed or grazed in 1973.

Before the arrival of the breeding waterfowl in spring, we determined range site (Dodds and Galt 1973), range condition (Dyksterhuis 1949), and mulch condition for native plant communities, and plant species composition and mulch condition for the tame plant communities. Mulch condition, meaning the stature of the residual vegetation, was determined by visual observation and described as being either upright (standing) or matted (fallen over).

Nest searching was conducted between 0800 and 1700 hours with the use of a cable-chain drag (Higgins et al. 1969). Two nest searches were conducted on each WPA between May 7 and June 27, with an approximate 25-day interval between the two. Nests were examined to determine waterfowl species, stage of incubation (Weller 1956), vegetation height, nest concealment, and plant species composition. Cover density height was determined by the method of Higgins and Kantrud (1973). Nests were revisited after the estimated date of hatch to determine success. Calculations for nest success included differences in exposure time of individual nests as recommended by Mayfield (1961). Consequently, nest success is not represented by a simple fraction conversion to a percentage basis.

Results and Discussion

Native and Tame Plant Communities Combined

A total of 263 waterfowl nests were located in the study area. Blue-winged teal accounted for 210 (79.8%) of the nests (Table 1). This proportion was considerably higher than the proportion (38%) of blue-winged teal found nesting in north-central South Dakota during 1971-73 by Duebbert and Lokemoen (1976). During 1974, blue-winged teal accounted for 59% of the pairs of surface-feeding ducks east of the Missouri River in an area that was comparable with ours (Brewster et al. 1976).

Nest success for blue-winged teal as well as for all waterfowl species was 43% (Table 1). This is considerably lower than the 70% suggested as the objective for nest success on managed areas (Kalmbach 1939).

Native Plant Community vs. Tame Plant Community

The native plant community made up 451 ha (47%) and the tame plant community 515 ha (53%) of the 966 ha of upland habitat searched on the study area. Nests of all waterfowl combined were more numerous in the tame plant community, which had 56% of the nests or 28.7 nests/km², compared to the native plant community, which had 44% of the nests or 25.6 nests/km² (Table 1).

Nesting densities of blue-winged teal were slightly greater (23.1 nests/km²) in native plant communities than in tame plant communities (20.6 nests/km²). With the exception of teals and shovelers (*Anas clypeata*), waterfowl preferred the tame plant community by about a 3 to 1 ratio (Table 1).

Nest success for all waterfowl was considerably higher in the native plant community (50%) than in the tame plant community (36%). Blue-winged teal nest success was 49% in the native plant community and 36% in the tame plant community (Table 1).

Native Plant Community

Range Condition

Range condition reflects the health of the native plant community and is defined as the percentage of vegetation present that is climax vegetation for the site (Dyksterhuis 1958). Waterfowl nest density was highest (26.4 nests/km²) on rangeland in excellent condition. As range condition deteriorated, nest density decreased accordingly (Table 2). Nest success was highest in native plant communities in fair (67%) and excellent (61%) range condition.

Kentucky bluegrass invasion into the native plant community was the most important factor causing the deterioration of range condition below the "excellent" category. Improper timing of grazing, haying, or burning may result in range deterioration. Overgrazing as well as excessive rest periods may favor bluegrass invasion into native plant communities (Cosby and Berlinger 1973).

Mulch Condition

The residual plant material from the vegetative growth of the previous year or years often is used for duck nests. Nest density was higher on sites with the matted mulch (32.2 nests/km²) than on sites with the upright mulch (24.0 nests/km²). Of the waterfowl nests in matted mulch, 66% were successful as compared with 45% in vegetation with upright mulch (Table 3).

Matted mulch is generally associated with long rest periods and/or natural forces such as prolonged periods of heavy snowpack. As excessive mulch accumulates, the range condition deteriorates because native grass growth is depressed. The stature of the mulch (matted vs. upright) appears to be more

Table 2. Duck nest density and nest success in relation to the range condition of the native plant communities, 1974.

Range condition	Nests found	Density (nests/km²)	Percent success
Excellent	19	26.4	61
Good	57	25.4	38
Fair	25	24.0	67
Poor	11	22.4	30

Table 3. Duck nest density and nest success in matted and upright mulch condition within native plant community, 1974.

Mulch condition	Hectares searched	Density (nests/km²)	Nests found	Percent success
Matted	87.5	32.2	25	66
Upright	363.2	24.0	87	45

important in relation to duck nesting rather than the amount of mulch material that accumulates from year to year. Proper maintenance of native plant communities requires some type of periodic manipulation to attain or maintain excellent range condition.

Tame Plant Community

Plant Groups

The tame plant community was subdivided into six plant groups consisting of alfalfa (*Medicago sativa*); alfalfa-tame grass mixtures, Kentucky bluegrass, smoothbromegrass, or intermediate wheatgrass (*Agropyron intermedium*); sweet clover mixture (*Melilotus* sp.), smooth bromegrass, intermediate wheatgrass; and forbs or annual grasses (Table 4). Nest density was highest (185.7 nests/km²) in the forbs and annual grasses, however, this figure is misleading because there was only one nest in the 6.7 ha of that plant group. The other 12 nests within this category were in small stands of forbs or annual grasses within tracts of vegetation represented by the other five plant groups.

The nest density of 54 nests/km² for smooth bromegrass was higher (Chi-square, $P \leq 0.05$) than the densities in the other major plant groups. Smooth bromegrass accounted for 24% of the 515 ha in tame plant communities, but contained 46% of all nests and 49% of the blue-winged teal nests, thus re-emphasizing the preference of blue-winged teal for smooth bromegrass as nesting sites (Table 4).

Low waterfowl nest densities occurred in homogeneous bromegrass stands in North Dakota (Salyer 1962, Schrank 1966), but bromegrass in small blocks was used extensively (Schrank 1966). The largest block of bromegrass in our study area, 34.4 ha, contained 8 duck nests. Other homogeneous bromegrass stands of 12.6, 8.9, and 6.9 ha contained 9, 12, and 6 duck nests respectively.

Blue-winged teal accounted for 72% of the waterfowl nests in the tame plant communities. The low nest densities in alfalfa (10.1 nests/km²) and sweet clover mixture (12.7 nests/km²) in our study undoubtedly are related to the predominance of nesting by blue-winged teal and their preference for grassland communities. High duck nest densities have been found in homogeneous stands of alfalfa or sweet clover mixtures (Salyer 1962; Duebbert and Kantrud 1974) when the nesting population consisted primarily of mallards (*Anas platyrhynchos*), gadwalls (*Anas strepera*), and pintails (*Anas acuta*).

Mulch Condition

Within the tame plant communities duck nest density was 28.4 nests/km² in the matted mulch and 28.8 nests/km² in the upright mulch (Table 4). Nest densities were similar for both matted and upright mulch within each plant group where both mulch conditions were available for sampling (alfalfa, alfalfa-tame grass mixture, smooth bromegrass, and intermediate wheatgrass).

Waterfowl nest success for the overall tame plant community was higher where the mulch was matted than where it was upright (49 versus 35%, Table 4). The higher nest success in the matted mulch was noted for the native plant community also. Nest success within the various plant groups in both the matted and upright mulch was variable. The high nest success in the alfalfa-tame grass mixture (73%) and smooth bromegrass (67%) with matted mulch suggests that such a combination may help deter predation on waterfowl nests in tame plant communities.

Management Recommendations

Habitat acquired as WPA's has the potential to produce substantial numbers of waterfowl. Because many WPA's are poor quality upland nesting habitat at the time of acquisition, nesting habitat improvement should receive attention from managers. Manipulation to improve upland cover should be based on the composition of local waterfowl populations and on nesting requirements for the most common species.

Our results as well as those of three Iowa studies (Bennett 1938; Glover 1956; and Burgess et al. 1965) suggest that blue-winged teal production increased following grazing. Both nest density and nest success for blue-winged teal in South Dakota were higher for native plant communities in excellent range condition. Management can attain these conditions by proper use of burning, grazing, resting, and haying.

Native plant communities with matted mulch had the highest nest success and nest density. In our study area, matted mulch resulted after rest periods from 1 to 3 years, but longer rest periods tended to degrade the range condition. The appropriate rest period for each native plant community should be based on range site, climate, and weather.

Smooth bromegrass had the highest nest density of all tame plant groups. More nests were successful in the tame communities when mulch was matted rather than upright. The best manipulations for tame grass groups to enhance waterfowl production are unknown. However, in our study area tame plant groups had been rested for at least 4 years and as long as 9 years. Apparently, high populations of nesting blue-winged teal can be

Table 4. Nest density and nest success in the matted and upright mulch conditions and percent nests in the tame plant groups, 1974.

	All nests			Matted mulch		upright mulch	
Plant community	Density (nests/km²)	Percent area	Percent nests	Density (nests/km²)	Percent success	Density (nests/km²)	Percent success
Smooth bromegrass	54.0	24	46 (68)[1]	45.4 (10)[1]	67	55.8 (58)[1]	39
Alfalfa mixture	28.2	20	20 (29)	21.6 (8)	73	31.8 (21)	32
Intermediate wheatgrass	25.6	8	7 (10)	33.3 (1)	9	25.0 (9)	64
Alfalfa	10.1	27	10 (15)	12.5 (5)	0	10.1 (10)	48
Sweet clover mixture	12.7	20	9 (13)	(1)	100	11.8 (12)	9
Forbs and annual grasses	185.7	1	9 (13)	(4)	13	128.6 (9)	14
Total				28.4 (29)	49	28.8 (119)	35

[1] Number of nests.

maintained on WPA's during wet cycles if native plant communities are in excellent range condition or if smooth bromegrass stands are established on lands previously under cultivation.

Conclusion

The use of range condition and range site to assess the successional status of native prairie in relation to climax provides a means of assessing conditions at the plant community level rather than dealing with specific plant species or given vegetation densities or heights. Our data suggest that native prairie can be made most attractive to nesting blue-winged teal by grazing with the intent to reach a specific range condition. Although grazing and haying are used on the WPA's in South Dakota, burning is a viable alternative. A similar understanding of tame plant groups in relation to soil types and plant species requirements for establishment and maintenance is needed for achieving optimum management for upland nesting habitat.

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Interactions between Mule Deer and Cattle on Big Sagebrush Range in British Columbia

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Abstract

Interaction between deer and cattle took various forms. The potential for direct competition was greatest in spring. Both deer and cattle selected bluebunch wheatgrass and crested wheatgrass while Sandbergs bluegrass was most often used by deer. Evidence of indirect interaction was observed. Moderate or heavy fall grazing by cattle made the spring forage more attractive to deer by removing mature forage. Light grazing did not exert any appreciable effect on deer distribution.

The spring range of mule deer in south central British Columbia is relatively restricted, usually below 775 m elevation. This range is also used by cattle in both spring and fall, providing forage at a time crucial to a viable ranching operation. Common use of the range ensures that interaction between cattle and deer will occur. The type and extent of interaction was not known but was believed to be most critical in the food niche. A project was initiated in 1972 near Kamloops, British Columbia, to study interaction between the two species of ungulates for the range resource in terms of food, time and space. The study was supported by the Agriculture Canada Research Station, the British Columbia Fish and Wildlife Branch, and the British Columbia Ministry of Forests. Some of these have been reported previously (Tucker et al. 1976; Willms et al. 1976; McLean and Willms 1977; and Tucker et al. 1977).

Site Description

The study area was on the north side of Kamloops Lake, about 24 km west of Kamloops. This area lies within the big sagebrush (*Artemisia tridentata*), ponderosa pine (*Pinus ponderosa*), and Douglasfir (*Pseudotsuga menziesii*) zones. The land rises steeply from the lake, at 335 m, to a series of knolls and a relatively flat area before rising again within the open forest. Maximum elevation on this range is 760 m. Snowfall is light and the direct southern exposure promotes early growth and a warm environment. The range had been heavily grazed from 1947 until 1965, when the grazing permit was cancelled to allow rehabilitation of overgrazed areas. One hundred hectares on the flat area were seeded to crested wheatgrass (*Agropyron desertorum*) in 1968.

Cattle normally use this range from early November to mid-December and again from early April to the end of May. The same area may be occupied by deer from early December to the end of May, although the greatest use occurs in a 1-month period in March and April. Some deer may remain on this range into the summer.

Methods

Four habitats were recognized on the study area. The forested range was considered as one and occupied 38% of the area. Three habitats on the open range, identified by topography, were a steep south-facing slope, a series of knolls, and a flat field, representing 15, 34 and 13% respectively of the total area.

Three hundred and seventy hectares were fenced to include both grassland and open forest. This area was divided into three fields, identified as east, west, and middle, each containing both open and forested range. A 1-ha deer and cattle exclosure was built in each field. These exclosures were located in the big sagebrush-bluebunch wheatgrass (*Agropyron spicatum*) community on a south-facing slope.

From 1972 to 1974 the grazing rotation was fixed. The east field was grazed only in fall, the middle field was grazed only in spring and the west field was grazed in both spring and fall. Since 1974, no field was grazed twice annually in consecutive years. Grazing pressure in each field varied from year to year but averaged 2.8 ha per animal-unit-month (AUM). Changes in deer distribution were studied to assess grazing treatments in those fields.

Vegetation Surveys

Two paired 1-m^2 plots were established at 10 randomly selected locations in each habitat to estimate plant cover and forage utilization. The percent ground cover of every major species was estimated on each plot. An additional estimate of basal area for each perennial grass species was made in the spring. In both spring and fall, one pair of plots was harvested before and after cattle grazing. Forage production during the grazing period was estimated from sites protected by wire cages and the information extrapolated to the harvested plots by a relationship derived for weight (y) and basal area (x) of each major plant species. Consumption was calculated to be the difference between the first harvest plus subsequent growth and the second harvest.

Cattle and Deer Distribution

Cattle distribution was evaluated by direct observations made periodically during daylight hours in both spring and fall. Distribution of deer was studied using animal count, track counts, and pellet group counts. Animal counts were made from a road at irregular intervals during the day. Track counts were sampled on two 100-m long transects located parallel to the contour in both the tree and south slope habitats. In the winter of 1971-72, tracks in the snow or mud could be surveyed until mid-March. After this period, 147 direct sightings were made. In the next winter the tracks could be surveyed until the end of February and then 93 direct sightings were made.

Pellet group counts were sampled prior to the reintroduction of cattle to study site and in the spring of each year thereafter. The first sample was made using a temporary belt transect extending perpendicular to the contour through each habitat. The belt was 2 m wide and partitioned into plots 20 m long. A permanent sampling system was later established. One transect was placed in each field to run parallel to the contour so that each habitat was sampled. Clusters of five circular plots, were spaced at intervals of 60 m on each transect. The plot diameters were 3.4 m and the cluster diameters were 32 m. Pellet groups were counted every spring starting 1972.

Pellet group distribution provided an indication of relative use by deer in each habitat prior to grazing and in each field following

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grazing. The impact of cattle grazing on deer distribution was evaluated by comparing the relative change in pellet group counts from one year to the next.

Cattle and Deer Diets

The proportion of grass species in spring cattle diets was estimated by separating each at the time of the utilization surveys. No separations were made in the fall. The spring observations were for 2 years while the fall observations were for only 1.

Two rumen-fistulated, identical twin beef cows were used to study forage selections by cattle. The animals were turned onto the range with other cattle during the normal grazing period in both spring and fall. Rumen samples were collected from each animal every 2 or 3 days during this period. The samples were washed on a 2.4 mesh/cm screen, air dried and hand separated to species with grass and grass-like species being pooled. The components were then oven-dried and weighed.

Rumen samples were collected from sacrificed free-ranging deer on the study area and from hunter- or road-killed animals nearby. Preparation for species separation and identification was the same as described above. Separation was modified with point sampling where the number of species in the sample was large. Grass and alfalfa were removed from the analysis when it was evident they originated from a domestic hay source.

Direct observations on tame deer were used to supplement the rumen data. Three deer were observed from mid-February to the end of May on the knoll and flat field habitats. Forage selection was evaluated by the number of bites taken from each species. A bite was counted only when forage was prehended and ingested.

Winter forage selection by free-ranging deer was determined by following deer trails in the snow and counting the number of browsed stems on nearby plants. The contribution to the diet was calculated for each forage.

Statistical Analysis

Vegetative cover was expressed as percent of ground cover and forage contribution to the diet as percent of the total diet. Means and standard error of the means were calculated from the raw data. When analysis of variance were used to test the hypothesis, the data were transformed using the arcsine square root transformation (Goulden 1952). Analysis of variance was used to compare cattle and deer diets among seasons.

Results and Discussion

Vegetation Survey

The forage composition among the fields was similar. Crested wheatgrass dominated the flat-field habitat of the east (19%) and middle (29%) fields but also occurred on the tree habitat of the west field (6%). Bluebunch wheatgrass was the dominant forage on the tree habitat in each field ($\simeq$23%) as well as a major representative on the south-slope habitat ($\simeq$10%). It dominated on the knoll habitat of the west field (19%) but was minor on that habitat in other fields. Sandbergs bluegrass (*Poa sandbergii*) decreased from the east to west fields. Needleandthread (*Stipa comata*) was also represented in major proportion in all habitats except the tree. Other grasses present, in decreasing order of importance, were cheatgrass (*Bromus tectorum*), sand dropseed (*Sporobolus cryptandrus*), Junegrass (*Koeleria cristata*), three-awn (*Aristida longiseta*), and rough fescue (*Festuca scabrella*).

Cattle Distribution

Not all cattle were located in each observation. The probable distribution of those not accounted (Table 1) was primarily the tree habitat and secondarily the knoll habitat, based on the searchability of each.

Cattle distribution in fall appeared influenced primarily by forage availability and weather. In the first fall, cattle preferred the flatfield habitats, moved onto the flat-field and, occasionally, intercepted the knoll habitats, then back to the waterholes, where they normally rested. Resting also occurred anywhere along the feeding area when weather was favourable. During wind storms, however, the animals were more likely to be found in the shelter of the trees near the waterhole and less often in the depressions of the knoll habitat. Major changes in the distribution patterns of cattle did not occur till late in the grazing period when the combination of snowfall, low temperatures, and heavy utilization of the flat-field habitat caused cattle to increase their use of the tree habitat where bluebunch wheatgrass protruded above the snow.

The second fall (1973) was characterized by periods of snowfall and melt. During warm periods most cattle use occurred on south-facing slopes where wind and snow melt first exposed the forage. During intermittent periods of snowfall and cold weather, cattle occupied the tree habitat. This resulted in very little forage utilization on the flat field but a proportionately higher degree of use on other habitats (Table 2).

Table 2. Consumption (percent estimated from clipping studies) of grass by cattle in each habitat during spring and fall.

Period and observations	Habitat: South slope	Knoll	Flat field	Tree
Fall 1973				
Utilization	58	19	8	23
Contribution to grass intake	29	21	4	45
Spring 1973 and 1974				
Utilization	49	47	71	25
Contribution to grass intake	17[1]	19	36	28

[1] Values are the amounts of forage removed from a habitat as a percentage of the forage removed from all habitats.

In spring the proportion of occupation and use was greatest on the flat-field habitat and least on the south-slope habitat (Tables 1 & 2). This may partly be explained as the reluctance of cattle to use steep slopes (Mueggler 1965). On the other hand, the tree habitat was not steep but, compared to the flat-field habitat, was used much less. Presumably the water holes, located near the edge and outside of the tree habitat, did not encourage use of that range. Another factor not well understood is forage quality.

Table 1. Daytime cattle distribution (percent) for 2 years on spring and fall range.

Period	n	South slope	Knoll: Range	Knoll: Waterhole	Flat field	Tree-open ecotone	Tree: Range	Tree: Waterhole	Cattle not counted
Fall 1972	757	1	11	0	19	8	5	29	27
Fall 1973	545	27	14	0	16	3	35	0	5
Spring 1973	1755	9	6	5	20	10	14	19	17
Spring 1974	256	0	17	0	41	20	2	0	20

Marquiss et al. (1974) found crested wheatgrass to be more palatable than bluebunch wheatgrass. In this study crested wheatgrass was also utilized to a considerably greater degree than the latter species.

Deer Distribution

Deer distributed themselves on spring range according to a diurnal pattern modified by external factors. Prior to cattle grazing, the deer used the south-slope, knoll and tree habitats to a similar degree throughout the season and used the flat-field habitat very little. The average number of pellet groups counted per plot in each habitat, and the standard error of their means, were 6.1±0.8, 5.7±0.5, 8.4±0.6, and 1.0±0.8 from the first to the last habitat mentioned above. Periodic shifts in daytime distribution occurred in both winters that track and animal counts were made. In the first winter, use shifted from the tree habitat (95%) in January to the warm open south-facing slope (60%) at the end of February. Deer use continued on the south-slope and knoll habitats until early May (82%) when use again shifted to the trees (90%). In the second winter and spring most direct observations were made in the tree habitat (68%) while use of the open habitats was limited (32%) and occurred in April. It is possible the open habitat was used primarily for night feeding. Decline in use may have occurred that year as a result of low forage quantity and palatability on the open range. Low soil moisture and warm temperatures reduced forage production and accelerated phenological progression. This effect would be less severe in the tree habitat, where trapped snow and shade inhibited snow melt and evaporation.

Cattle Diets

Clipping studies in fall showed that the degree of grass use was greatest on the south-slope habitat and least on the flat-field habitat (Table 2). However, the tree habitat contributed most to total grass consumed. In spring, the degree of grass use was greatest on the flat-field habitat and least on the tree habitat. The flat-field habitat also contributed more to total grass consumed than did the other habitats (Table 2).

Grasses dominated the cattle diet in both seasons, as observed in rumen samples. Although the difference was small, the percentage of grass consumed was significantly ($P\leq0.05$) greater in spring (95.0) than in fall (91.9). Most of the remaining proportion consisted of tree species. The percentages of bluebunch wheatgrass, crested wheatgrass, and needleandthread in the diet were estimated from the clipping studies to be 41, 23, and 25%, respectively. The remaining 11% was made up of Sandbergs bluegrass, Junegrass, and sand dropseed. The degree of use of the three major species were: bluebunch wheatgrass 40%, crested wheatgrass 79%, and needleandthread 51%.

A major contributor to the forb component of the diet in fall was bassia (*Bassia hyssopifolia*). Important shrubs were pasture sage (*Artemisia frigida*) and rose (*Rosa* spp.) in both seasons. Ponderosa pine dominated the tree component of the diet in spring and shared dominance in fall with Douglasfir.

Cattle selected primarily bunchgrasses in both spring and fall. Utilization of Sandbergs bluegrass was not observed in either season and could not be estimated from the clipping trials because of its short leaf length. Skovlin et al. (1976) showed that Sandbergs bluegrass was used to some extent by cattle in Oregon, where it appears to grow taller.

Deer Diets

The presence of grasses, forbs, shrubs, and trees varied considerably in the rumen samples of deer from mid-September to the end of April (Table 3). Grasses dominated the spring diet, while forbs declined from 23% in fall to 4% in spring. Shrubs were used extensively in both fall and mid-winter but were minor components in early winter and spring. Trees dominated the diet in early winter.

The species composition of grass was estimated from observations of tame deer. From mid-February to the end of May, deer diets on the knoll habitat averaged 21% bluebunch wheatgrass and 55% Sandbergs bluegrass. The percentage of bluebunch wheatgrass remained relatively uniform throughout this period but the contribution of Sandbergs bluegrass ranged from 88% in March to 6% in May. Cheatgrass was selected only in May when it comprised 24% of the diet. Junegrass increased from 2% early in the period to 18% in May.

On the flat-field habitat Sandbergs bluegrass ranged from 94% of the grass component in the diet in late February to 3% in May. Crested wheatgrass was next in importance, increasing from 6% in February to 55% in May. Other species, in order of their importance in the grass component of the diet, were bluebunch wheatgrass, cheatgrass, Junegrass, and needleandthread. The species representing the forb component in the rumen samples varied throughout the period from mid-September to the end of April. In the first month the major species was tall wormwood (*Artemisia campestris*); but in November, asters (*Aster* spp.), thistle (*Cirsium arvense*), and twinflower (*Linnaea borealis*) were important. Cactus (*Opuntia fragilis*) was also a major forb in the diet during December and January.

The shrub component also varied in the rumen samples. From mid-September to the end of November, the evergreen shrubs, false box (*Pachystima myrsinites*) and Oregon grape (*Berberis repens*), dominated. In winter and spring, however, the shrub component consisted primarily of pasture sage, big sagebrush, and rabbitbrush (*Chrysothamnus nauseosus*), in approximately equal proportions.

The tree component consisted almost entirely of Douglasfir. In late winter ponderosa pine represented about one-quarter of the tree component.

Deer Winter Diet

The winter diet of deer in the study area consisted mostly of

Table 3. Composition (percent) of grasses, forbs, shrubs, and trees in the rumens of free ranging mule deer for five periods from September 15 to April 30.

Plant type	Period (Number of samples)				
	Sept. 15-Oct. 31 (7)	Nov. 1-Nov. 30 (20)	Dec. 1-Dec. 30 (17)	Jan. 1-Mar. 15 (14)	Mar. 16-Apr. 30 (9)
Grasses	1.6±0.6a	2.7±0.2a	0.2±0.2a	3.1±0.5a	64.0±1.9b
Forbs	23.0±1.9a	21.2±1.1a	15.2±1.2a	11.7±1.2a	4.0±0.9a
Shrubs	53.9±2.0b	47.3±1.2b	17.1±1.0a	50.7±1.5b	11.4±1.0a
Trees	3.6±0.7a	22.5±1.0ab	63.9±1.3c	33.0±1.5b	19.8±1.6ab
Nonvascular	17.9±1.5b	6.3±0.7a	3.6±0.7a	1.5±0.4a	0.8±0.4a

a,b,c. Figures followed by the same letter in rows are not significantly different ($P\leq0.05$) according to Duncan's multiple range test.

Table 4. Defoliation, by deer, of plants found near tracks in the snow: and average snow depth for January and February in 2 years.

Species	1972			1973		
	Number plants available	Plants used (%)	% of total stems used	Number plants available	Plants used (%)	% of total stems used
Forbs						
Artemisia campestris				363	4	1.0
Calochortus macrocarpus				49	65	2.1
Chenopodium album				58	93	3.5
Cirsium sp.	1	100	0.1	11	91	0.6
Medicago sativa				5	60	4.2
Penstemon procerus				2	100	0.9
Tragopogon dubius	11	36	0.4	153	86	8.4
Shrubs and trees						
Artemisia frigida	375	1	2.2	129	50	32.3
Artemisia tridentata	120	9	25.6	1	0	
Chrysothamnus nauseosus	80	32	60.6	145	39	44.5
Juniperus spp.	6	67	7.1	4	0	
Pinus ponderosa	3	33	0.2	2	0	
Pseudotsuga menziesii	21	29	3.6	11	55	2.5
Rosa spp.	2	50	0.1			
Total			100			100

	1972	1973
Number surveys	6	9
Total survey lengths (m)	508	745
Number stems utilized	987	1559
Average snowdepth (cm)	35	2

Douglasfir, which appeared to be supplied primarily from branches that had frozen and broken off. Foliage from these branches was readily eaten and appeared to be very palatable. The branches came mainly from the upper part of old trees where agitation by wind is greatest and dislodgement more likely to occur. Tucker et al. (1976) found palatability to increase from the bottom to the top of old Douglasfir trees. The availability of this material is sporadic, however, and seems dependent on the depth of snow (Willms et al. 1976). In the first winter (Table 4) deep snow discouraged use of pasture sage, which resulted in greater use of the taller shrubs, big sagebrush and rabbitbrush. In the next winter, snow was not a factor and both pasture sage and forbs were used extensively. The role these forbs play in deer nutrition is not known. Their contribution to the macronutrient intake cannot be considered important as they are low in crude protein (i.e. 3%) and presumably in digestible energy. They may, however, be sources of some micronutrients.

Although big sagebrush contributed 26% of the diet, only 7% of available plants were used (Table 4). It would appear that individual plants were grazed repeatedly while neighbouring plants were unused. Hanks et al. (1971) attributed this phenomenon to genotypic variation which they were able to distinguish by examining the composition of phenolic compounds. Similar work was done on rabbitbrush (Hanks et al. 1975) and Douglasfir (Radwan 1972).

Deer Spring Diet

Forage selection be deer in spring appeared to be in response to palatability and availability. The first new grass that became available was Sandbergs bluegrass. It was palatable forage and eagerly sought after by deer. Although leaf emergence in bluebunch wheatgrass and crested wheatgrass was only a few weeks later than Sandbergs bluegrass, its availability was related more to the extension of new tillers above the barrier of standing old growth. Availability of those two species was, therefore, related to the degree of prior fall grazing by cattle. The availability of bluebunch wheatgrass to deer on grazed sites was generally limited before mid-April and abundant after that time.

Sandbergs bluegrass loses its palatability early in the season. Its shallow root system, a characteristic that ensures early spring growth, is responsible for early maturity as the plant responds to soil moisture depletion. The dependence of Sandbergs bluegrass on spring moisture results in high year-to-year variation in productivity and rate of maturity.

Table 5. Average change x̄±SEm) in the ground cover of major plant species, in relation to grazing, from June 1971 to June 1974 on the knoll habitat (n=6).

	Ground cover (%)			
	Grazed		Ungrazed	
Species	East	Middle	West	(3 fields combined)
Agropyron spicatum	+1.2±2.2a	−0.4±1.9a	+0.8±21.a	+3.0±1.2a
Artemisia tridentata	+0.5±0.6a	+1.5±3.1a	−5.7±1.9a*	−0.6±0.7a
Bromus tectorum	+2.3±0.8ab*	+10.2±4.0c*	+8.0±3.7bc*	+1.5±0.9a*
Poa sandbergii	+2.3±1.2a*	+3.0±1.1a	+0.3±0.8a	+2.3±0.6a*
Stipa comata	−7.0±2.0b*	−14.8±1.1c*	−7.2±1.7bc*	−2.6±1.4a*

a,b,c Figures followed by the same letter in rows are not significantly different according to Duncan's multiple range test ($P \leq 0.05$).
* Change in cover between years is significantly ($P \leq 0.05$) greater than zero.

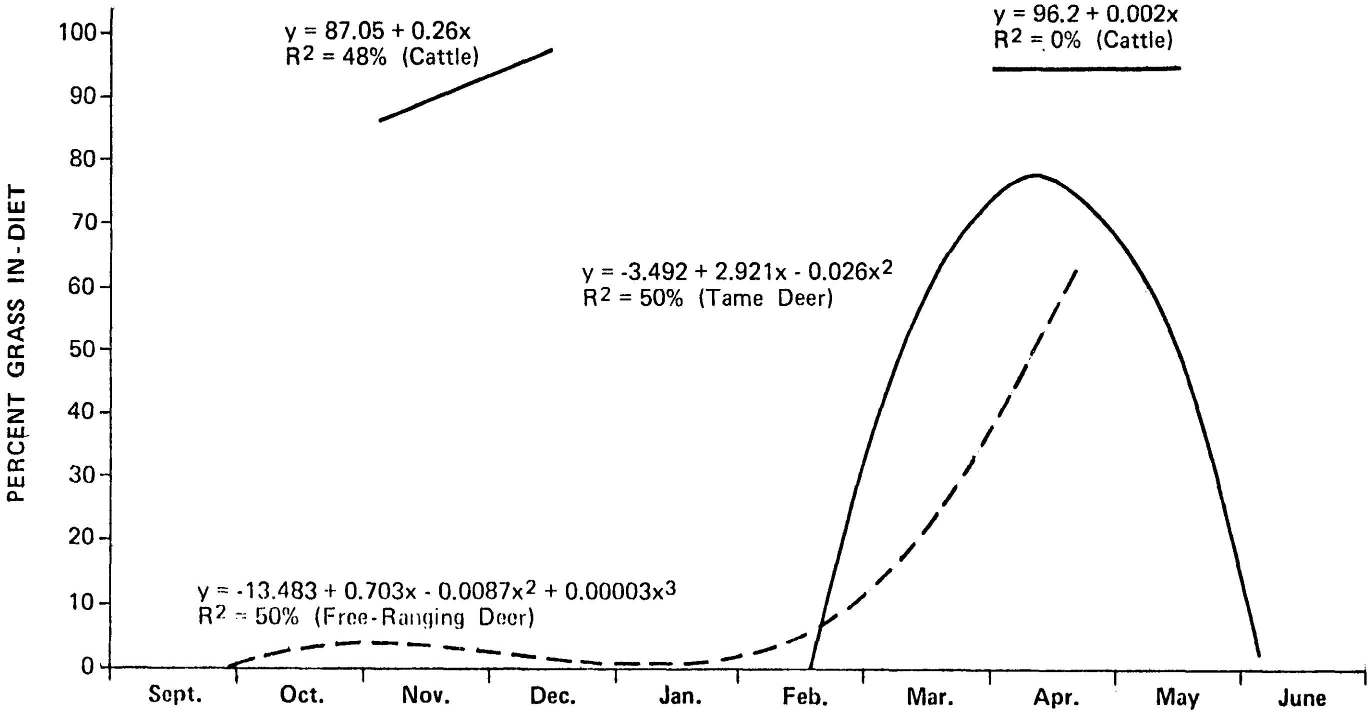

Fig. 1. *Polynomial regressions describing the proportion (percent) of grass in the diet of deer and cattle on both spring and fall ranges (x in days; day 1 for each regression is: cattle in fall, Nov. 3; cattle in spring, April 2; free-ranging deer, Sept. 15; and tame deer, Feb. 14)*

Direct Deer-Cattle Interaction

Although the species composition of grass used by free-ranging deer was not known, the use of that type by tame deer was similar where comparisons could be made (Fig. 1). The greatest potential for competition was for grass in spring. Two conditions occurred which negated realization of this potential. One was the species composition of the grasses. Cattle preferred crested wheatgrass growing on the flat-field, and it along with bluebunch wheatgrass and needlethread, formed the bulk of their diet in April and May. Utilization of Sandbergs bluegrass by cattle was low. Deer diets in April, on the other hand, were dominated by Sandbergs bluegrass. Bluebunch wheatgrass and crested wheatgrass, however, became major constituents in their diets in May. It is in this month that competition is most likely.

The second condition that minimized competition was the cattle grazing plan used. One field was vacant each spring. If social interaction between deer and cattle existed or if competition for food and space had occurred, the deer could have moved onto that field. This, of course, assumes that the deer population was low enough that the other field was not fully occupied. If it had been, competition would not have been alleviated.

Social interaction between deer and cattle is thought to be minor. Skovlin et al. (1976) and Julander (1955) reported that mule deer use did not decline on areas used jointly with cattle. Kraemer (1973) observed no interference between mule deer and cattle when the distance between them was greater than 47 m; avoidance was observed with shorter distances.

Table 6. Deer use determined by pellet group counts from three fields for 5 years and spring and fall cattle stocking levels for 4 years.

		East		Middle		West	
Year and Grazing period	Total deer pellet group counts in spring	Use (%)	Cattle stocking level*	Use (%)	Cattle stocking level*	Use (%)	Cattle stocking level*
1972	215	32		35		33	
Spring			Nil		Nil		Nil
Fall			High		Nil		Light
1973	64	56		25		19	
Spring			Nil		High		Light
Fall			Light		Nil		Light
1974	201	25		59		16	
Spring			Moderate		Light		Nil
Fall			Nil		Light		Moderate
1975	134	33		37		30	
Spring			Light		Nil		High
Fall			Light		Moderate		Nil
1976	384	31		43		26	

*Light, >3.6 ha/AUM; Moderate, 2.6 to 3.6 ha/AUM; High, <2.6 ha/AUM

Indirect Deer-Cattle Interaction

Fall grazing by cattle may affect deer distribution in spring. The year-to-year variation of distribution and use was observed with permanent pellet survey transects and compared to previous cattle grazing (Table 6). The 1972 counts followed 7 years of rest from cattle grazing and could be considered an indication of what distribution would be if cattle had not been allowed on the range. Use among the fields was even, indicating there was no selection for one field over the others. After the first grazing year (1973) there was a decline in the total number of pellet groups counted and a shift in use from the west and middle fields into the east field. The decline in use could be attributed to the mild winter of 1972-73, during which the deer remained on the upper ranges until early spring. The shift into the east field was in response to the heavy cattle grazing the previous fall which reduced the stubble height of bluebunch wheatgrass and crested wheatgrass. This ensured that spring growth was available to deer earlier in that field than in the others. The same response was noticed the following year when heavy spring grazing in the middle field was followed by a shift in deer use to that field. The next year (1974) all fields were grazed moderately and deer use again was divided evenly among fields. In the last year, deer use shifted to the middle field despite heavy fall use in the west field. The effect of heavy grazing was negated by two factors: one was a wet summer that allowed greater than normal vegetative growth so that the stocking level was moderate; the second factor was a fall fire in the middle field, which simulated the effect of heavy grazing. A 4-year summary of results, based on average percent use following four full stocking levels, is: nil grazing, 35%; light grazing, 26%; moderate grazing, 36%; and high grazing, 56%.

Spring grazing levels also demonstrated an effect on deer distribution. Average use following four stocking levels of that season were: nil, 34%; light, 26%; moderate, 33%; and high, 42%. The factors affecting this response are not clear. It is possible that spring grazing reduces litter buildup, thus reducing the barrier to green forage in the spring.

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Production Response of Native and Introduced Grasses to Mechanical Brush Manipulation, Seeding, and Fertilization

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Abstract

Effects of two mechanical brush manipulation treatments (rootplowing and front-end stacking) with and without grass seeding and with and without nitrogen fertilization on herbaceous forage production were investigated in the Rio Grande Plain of Texas. Total herbaceous production (4-year average) was 5,981 for rootplowing and 4,789 kg/ha for front-end stacking as compared with 2,178 kg/ha for the undisturbed control. The 4-year average yield of buffelgrass (*Cenchrus ciliaris* L. (L.) Link) seeded alone contributed 53% of total herbaceous production on plots with rootplowing, 73% on plots with front-end stacking, and 38% on control plots. The combined yield of three native species, pink pappusgrass (*Pappophorum bicolor* Fourn.), four-flower trichloris (*Trichloris pluriflora Fourn.*), and Arizona cottontop (*Digitaria californica* (Benth) Henr.), seeded as a mixture contributed 41% of the total herbaceous production on plots with rootplowing, 28% on plots with front-end stacking, and 11% on control plots. The application of 45 kg/ha nitrogen significantly increased total herbaceous production the season after application.

Population increases have caused concern about increasing needs for red meat as food source throughout the world. The key for increasing beef and wild game production is increasing native and introduced herbaceous plant production, thus making more food available to grazing animals and ultimately to man.

On the Rio Grande Plain in Texas, the invasion of woody plants and cacti has reduced available grass forage. About 85% (5.5 million ha) of the Rio Grande Plain rangeland supports at least a 20% brush canopy cover (U.S. Dep. of Agr. 1964). Conceivably, many range sites of the Rio Grande Plain are producing at only 25% of their forage potential, and much of the native rangeland of Texas is producing far below potential (Texas Conservation Needs Committee 1970).

Rootplowing, a mechanical manipulation practice that cuts off the brush below ground by means of a horizontal blade pulled behind a tractor, generally at a depth of 35 to 40 cm, has been highly effective in combatting dense stands of mixed brush. However, in low rainfall areas, the practice could destroy a large percentage of the desirable perennial grasses and cause the invasion of annual grasses and weeds (Fisher et al. 1959). Mathis et al. (1971) reported that in Throckmorton County, Texas, rootplowing decreased grass production for the next six growing seasons. In west Texas, Hughes (1966) reported more total production after rootplowing, but forbs and annual grasses constituted the major vegetation. In the coastal prairie of Texas, Powell and Box (1967) concluded that controlling brush with a minimum soil disturbance was the most reliable method for improving vegetative composition and increasing forage production. They also concluded that N fertilizer increased forage production, but also caused an increase in the amount of undesirable forage species.

Dodd (1968) reported that in the Rio Grande Plain, dragging followed by rootplowing resulted in the establishment of a relatively brush-free grassland with an increase in forage production.

Fisher et al. (1959) reported that seeding of grasses produced good stands of native and introduced grass species after rootplowing and disking in northwest Texas. However, on the Rolling and Southern High Plains, Jaynes et al. (1968) reported that seeding native grasses after rootplowing often resulted in unsatisfactory stands.

Front-end stacking, a recently introduced mechanical practice, has not been thoroughly evaluated. A front-end stacker is a modified dozer blade using a toothed, rake-like "stacker" with teeth 14 to 36 cm apart. The teeth pull up the plants by the roots. In the Coastal Prairie of Texas, Powell and Box (1967) found that scalping, a manipulation similar to front-end stacking, decreased herbage production.

In view of these inconsistent results of brush manipulation on forage production, we conducted this study to further evaluate the effects of rootplowing and front-end stacking with and without grass seeding and with and without N fertilization on herbaceous forage production on the Rio Grande Plains of Texas.

Materials and Methods

Study Area

The study area is on the southern edge of the Rio Grande Plain, about 38 km north of Rio Grande City, Starr County, Texas. Long-term average annual precipitation is 43 cm and is exceeded by potential evaporation four times (U.S. Dep. Commerce 1970). Most precipitation occurs as thunderstorms that are unevenly distributed both geographically and seasonally. Occasionally, tropical disturbances produce heavy fall rains; thus, September has the highest long term monthly rainfall average, with another rainfall peak in late May or early June from squall-line thunderstorms.

Summer temperatures are high, and daily maximum temperatures in July and August are usually 38°C or higher (U.S. Dep. Commerce 1970). Fall freezes occur 7 out of 10 years, and spring freezes occur 9

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out of 10 years. The average length of the growing season is 305 days (U.S. Dep. Commerce 1970).

The study area is a sandy loam range site with level to gently sloping topography (0 to 5%). The associated soil types are McAllen and Brennan sandy loams, which are soils with noncalcareous fine sandy loam surfaces and sandy clay loam subsoils. The Brennan series is a member of the fine-loamy, mixed, hyperthermic family of Aridic Haplustalfs; the McAllen series belong to the hyperthermic family of Ardic Ustochrepts. The fine sandy loam surface ranges from about 25 to 50 cm deep. Permeability of the subsoil is moderate. The water holding capacity and fertility of these soils are high; thus, this site has a high production potential.

The dominant woody plant species include cenizo (*Leucophyllum frutescens* (Berl.) I.M. Johnston), blackbrush acacia (*Acacia rigidula* Benth.), coyotillo (*Karwinskia humboldtiana* (R&S) Zucc.), coma (*Bumelia celastrina* H.B.K.), mesquite (*Prosopis glandulosa* Torr.), and capul (*Schaefferia cuneifolia* Gray). Brush density consists of about 4,900 plants/ha with 35% canopy cover.

Dominant grass species include Wright's threeawn (*Aristida wrightii* Nash.), Texas bristlegrass (*Setaria texana* Emery.), hooded windmill grass (*Chloris cucullata* Bisch.), and red grama (*Bouteloua trifida* Thrub.). Forb cover was sparse, with western ragweed (*Ambrosia psilostachya* D.C.), ragweed parthenium (*Parthenium hysterophorus* L.), rose palafoxia (*Palafoxia rosea* (Bush) Cory), and lazydaisy (*Aphanostephus skirrhobasis* (D.D.) Trel.) recurring as dominants.

Treatments

Mechanical treatments were established during June 1972 on native undisturbed brushland in poor condition due to overgrazing. A split-block design had main plots of two mechanical brush-manipulation treatments (rootplowing and front-end stacking) and an undisturbed control. Each replication or block consisted of three 2.4-ha strips, one strip each for rootplowing, front-end stacking, and the control. Each strip was divided equally into three 0.8-ha subplots, which were seeding treatments of (1) a single species, buffelgrass (*Cenchrus ciliaris* (L.) Link, at 2.2 kg/ha, (2) a mixture of five native grass species (Table 1), and (3) unseeded. Subplots were hand seeded between August 31 and September 6, 1972. Each subplot was split into two sub-subplots (0.4 ha each) with one receiving 45 kg/ha N and the other receiving no fertilizer. All treatments were replicated three times. Nitrogen (as ammonium nitrate) was applied about 1 year after seeding (August 1973). Thus, the experimental plot layout consisted of fifty-four 0.4-ha plots.

Table 1. Five native grasses seeded as a mixture and corresponding seeding rates.

Grass seed	Rate[1] (kg/ha)
Pink pappusgrass (*Pappophorum bicolor*)	0.4
Arizona cottontop (*Digitaria californica*)	0.7
Plains bristlegrass (*Setaria macrostachya*)	0.4
Two-flower trichloris (*Trichloris crinita*)	0.3
Four-flower trichloris (*Trichloris pluriflora*)	0.3

[1] Rates based on pure live seed.

A standard recording rain gauge was used to measure rainfall. Rainfall amounts recorded were 86, 60, 55, and 73 cm for 1973, 1974, 1975, and 1976, respectively.

All plots were deferred from domestic livestock grazing until January 1974. Then they were grazed from late spring to early summer and again in late fall each year. The number of animal units varied each year, but plots were grazed for 90, 140, and 135 days for 1974, 1975, and 1976, respectively, which was about 60% utilization each year.

Herbaceous forage production was determined by clipping all vegetation at ground level in twenty 0.5-m^2 quadrats on each subplot All grasses and forbs in each quadrat were identified, counted, and recorded. Each species was clipped separately and yields were determined by species. Vegetation samples were oven dried at 68°C, and yields were reported as oven-dried weight. Yields are accumulations of two harvests per year (June and November).

Soil infiltration measurements were determined in all subplots of one main plot replication with the technique described by Wiegand et al. (1966) using water from a nearby well containing 2,220 ppm total salts. Soil moisture before infiltration was determined gravimetrically.

During the study, soil moisture was determined by neutron scattering techniques (Stone et al. 1955). Access tubes were installed in all plots of one replication. Two tubes were located in each plot to a 90-cm depth. Soil moisture was measured weekly at 30-cm depth increments, and these data were converted to centimeters of water/30 cm of soil.

Plant nomenclature follows Gould (1969) and Correll and Johnston (1970). Data were analyzed statistically by the analysis of variance method (Cochran and Cox 1956).

Results

Before treatment, the study area supported a dense stand of

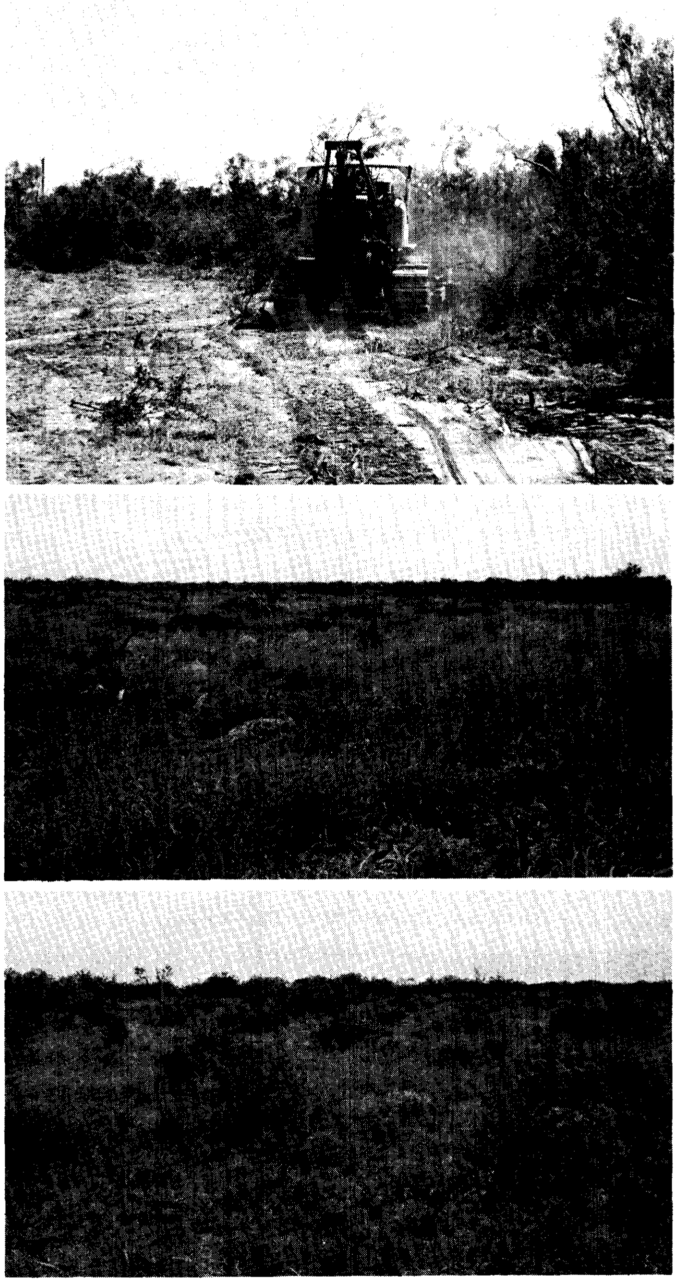

Fig. 1. *Vegetation condition in 1972 prior to mechanical brush manipulation (upper), 3 years after rootplowing and seeding to buffelgrass (center), and 3 years after front-end stacking and seeding to buffelgrass (lower).*

Table 2. Effects of mechanical brush manipulation and seeding on total herbaceous yield (kg/ha) for 4 years after treatment.

Seeding treatment	Mechanical treatments R.P.[1]	F.E.	C	Mean	R.P.	F.E.	C	Mean
	1973[2]				1974			
Buffelgrass	3518	5053	2165	3579a[3]	6839	7364	1548	5250a
Native mixture	4235	2446	1481	2721b	5390	4478	1740	3869b
Nonseeded	3106	2222	1754	2361b	4988	3963	2185	3712b
Mean	3620a	3240a	1800b		5739a	5268a	1824b	
	1975				1976			
Buffelgrass	8480	5532	1308	5107a	9261	7462	3384	6702a
Native mixture	5429	4122	1652	3734b	8595	5984	3397	5992a
Nonseeded	4503	3563	1578	3215c	7423	5277	3944	5548a
Mean	6137a	4406b	1513c		8426a	6241b	3575c	

[1] Mechanical treatments are rootplowing (R.P.), front-end stacking (F.E.), and undisturbed control (C.)
[2] Data are accumulations of 2 harvests/year.
[3] Values followed by the same letter are not significantly different within each year at the 0.05 probability level as determined by Duncan's multiple range test. Comparisons for manipulation and seeding are made horizontally and vertically, respectively.

woody species (Fig. 1); but 3 years later, after rootplowing and front-end stacking, woody plant density had decreased. Brush species were controlled more effectively with rootplowing than with front-end stacking, but forage production was increased by both mechanical treatments.

Total Herbaceous Production

Mechanical treatments, with and without grass seeding, significantly increased total forage yields (Table 2). Forage production from the root-plowing treatment was two, three, and fourfold greater than that of the control in 1973, 1974, and 1975, respectively. In 1976, production was higher for all three main treatments, which was attributed to the high rainfall received during the growing season. Rainfall greater than 2.5 cm was received every month from March to December. Buffelgrass was the main contributor to the high forage production for the control treatment in 1976. By 1976, buffelgrass had invaded all unseeded plots of the control treatment as well as those of the rootplowed and front-end stacked treatments. Mean yields for rootplowing and front-end stacking treatments did not differ significantly ($P<0.05$) from each other in 1973 or 1974, but both treatments had significantly higher forage production than did the control. In 1975 and 1976, forage yields from the rootplowed treatment were significantly higher than that from either the front-end stacking treatment or the control. However, yields from front-end stacking treatment were significantly higher than that for the control. Mechanical treatments interacted significantly ($P<0.05$) with grass seeding treatments in 1975.

When we compared seeding treatments, buffelgrass seeded plots produced significantly more forage than did the native mixture treatment and the nonseeded treatments for the first 3 years. In 1973, 1974, and 1976, herbage yields from the native mixture seedings and nonseeded treatments were not significantly different. In 1975, all three seeding treatments different significantly from each other with buffelgrass the highest yielder, followed by the native mixture, and then the nonseeded treatment.

The application of N significantly ($P<0.05$) increased total forage production only during the season after application (1974). Forage production was increased 20 and 12% over that of the control, respectively, for rootplowed and front-end stacked treatments (data not shown). There were significant interactions ($P<0.05$) between fertilizer and mechanical treatments. The interaction indicated better fertilizer response to rootplowing seeded to buffelgrass than for any of the other treatments.

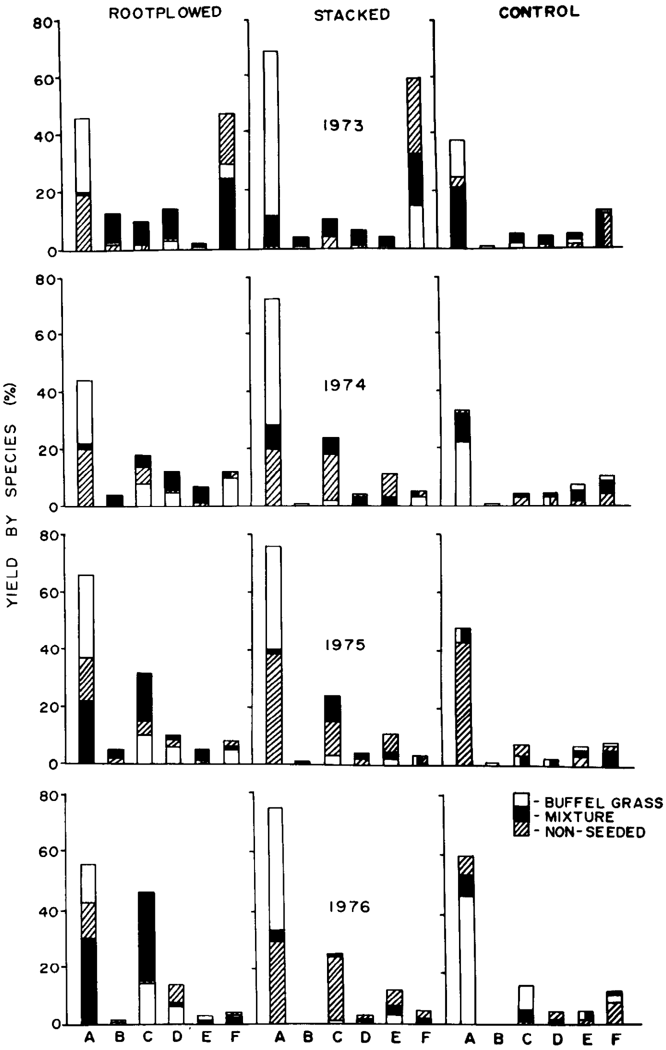

Fig. 2. *Herbaceous forage yields by species from 1973 to 1976 after rootplowing, front-end stacking, and no treatment and seeded to buffelgrass, a mixture of five native grasses, and nonseeded. Species were buffelgrass (A), plains bristlegrass (B), four-flower trichloris (C), Arizona cottontop (D), pink pappusgrass (E), and total forbs (F). Each bar represents percent of the forage produced by each species on each of the three seeding treatments.*

Forage Production by Species

The contributions of selected species to total herbaceous production under the mechanical treatments and the undisturbed control are shown in Figure 2. Buffelgrass was the most important single species contributing to forage yields regardless of treatment. Buffelgrass spread outside the seeded areas; moreover, the percent of buffelgrass production progressively increased from 1973 to 1976 on all treatments. The remaining herbage on the buffelgrass plots was primarily from nonseeded grasses and forb species.

In the mixture treatment, three seeded native species (pink pappus, four-flower trichloris, and Arizona cottontop) combined accounted for better than 20% of total yield all 4 years. The rest of the forage in this seeding treatment was produced by buffelgrass, voluntary nonseeded grasses, and forbs.

Major grass species on the nonseeded plots contributing to total herbage production included hooded windmill, Wright's threeawn, red grama, sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), Texas bristlegrass, and false witchgrass (*Leptoloma cognatum* (Schult.) Chase). However, these species accounted for less than 40% of the total forage each year. The remaining herbage on this treatment was produced mostly by buffelgrass, four-flower trichloris, and forbs.

Forb contribution to total production was high the first year for both mechanical treatments, but decreased with time the last 3 years. Major forb species contributing to herbaceous yield included rose palafoxia, western ragweed, ragweed parthenium, bristleleaf dogweed (*Dypsodia tenuiloba* (D.C.) Robinson), and espanta vaqueros (*Tidestromia lanuginosa* (Nutt.) Standl.).

Infiltration Relationships

During infiltration tests, the soil was uniformly dry. At the initial test (August 1972), the 0- to 90-cm soil depth moisture content averaged 6.3%. At the second test (January 1975), the 0- to 90-cm soil depth moisture content averaged 7.6%.

Initial infiltration rates for soil subjected to rootplowing and front-end stacking were significantly higher than that for the control (Fig. 3). However, 30 months later, there were no significant ($P<0.05$) differences between treatments. During the first 5 minutes of the initial test, the infiltration was 55.5, 31.9, and 17.0 cm/hr for rootplowing, front-end stacking, and control treatments. This accounted for about 35% of the total water infiltrated during the first 1-hr test for all treatments. Rootplowed plots had the fastest infiltration rate during the first 100 minutes, but after that, front-end stacking plots had the fastest rate. For all time intervals up to 120 minutes, rootplowing and front-end stacking treatment values were 2.5 and 1.7 times greater than those for the control, respectively.

Thirty months after the mechanical treatments were applied, the infiltration rate for the first 5-minute interval was 18.8 cm/hr for both mechanical treatments and 17.0 cm/hr for the control, which accounted for 51% of the total water infiltrated the first hour.

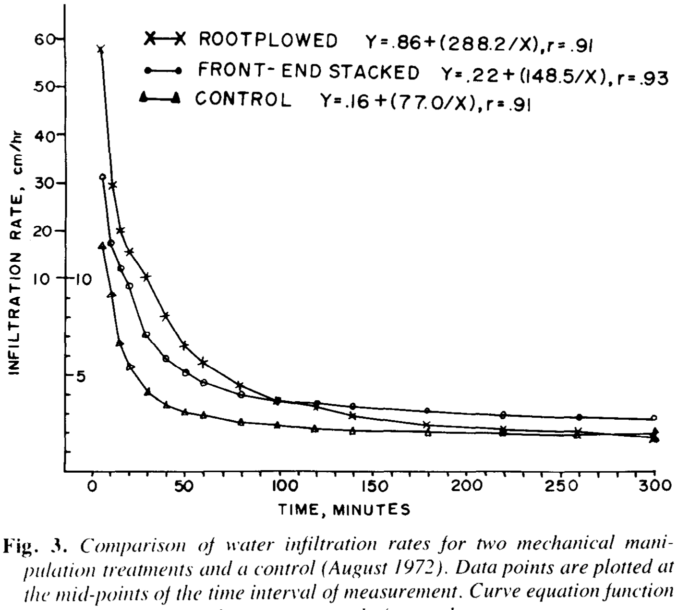

Fig. 3. *Comparison of water infiltration rates for two mechanical manipulation treatments and a control (August 1972). Data points are plotted at the mid-points of the time interval of measurement. Curve equation function and the regression value* (r) *are stated after each treatment.*

Water Relationships

Water use efficiency in grassland ecosystems is difficult to measure and interpret due to evaporation and transpiration losses, rainfall distribution patterns, varying amounts of ground cover, runoff, and soil disturbances.

Soil moisture data from March to December 1973 showed that initial soil moisture measurements were similar for all three treatments (Fig. 4). However, after June, soil moisture after rootplowing and front-end stacking was consistently higher than that for the control. Following high intensity rainfall (for example 16.5 cm in June and 22.2 cm in September), rootplowing and front-end stacking accumulated more soil moisture than did the control. Only in August, after only 0.50 cm of rainfall in July, was soil moisture depleted to about the same level on all treatments.

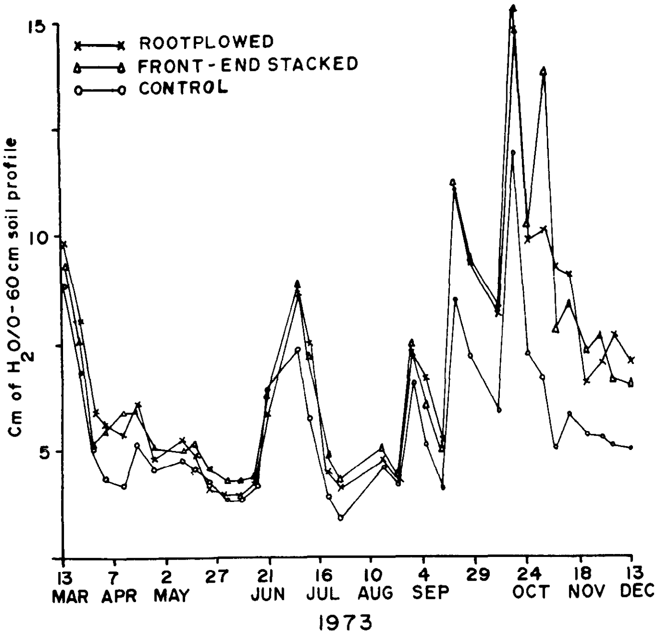

Fig. 4. *Soil moisture in 0- to 60-cm soil profile as measured weekly for three treatments. (Mar. to Dec., 1973).*

We compared soil moisture depletion for a 21-day period of no rainfall (July 5 to 26). On July 5, soil moisture at the 0- to 60-cm depth was 8.8, 9.0, and 7.5 cm of water for rootplowing, front-end stacking, and the control treatments, respectively. On July 26, soil moisture was 4.1, 4.4, and 3.5 cm for the three treatments, respectively.

When we measured soil moisture at the 0- to 90-cm depth, soil moisture after rootplowing and front-end stacking treatments was depleted by 0.33 cm/day as compared with 0.23 cm/day for the control. However, after 21 days, these two treatments still had more soil moisture for forage production than did the control, which reflected their higher infiltration capacity.

Discussion

Moisture data from this study helped to determine whether production increases are caused by more moisture in soil profile after brush removal and plowing (rootplowing) or more available moisture due to no plowing but less plant competition after woody plant removal (front-end stacking). It was apparent from the water infiltration and moisture use relationships that both mechanical treatments increased total forage production as compared with the control treatment. The large increase in production reflected the higher water infiltration rates and reduction in competition from woody plants after mechanical treatments. As a result, more soil moisture was available for plant growth of desired species. The increased grass herbage production during the 4-year study (seeded vs unseeded) was associated with the response of buffelgrass to above-average rainfall.

Buffelgrass herbage production in 1976 constituted about 44 and 51% of the total grass production on both mechanical and control treatments, respectively. Even though buffelgrass contributed a higher percent of forage on the control plots, total production was less due to lower plant density. However, invasions of buffelgrass plants on all treatments indicated this species' fast response to rainfall and its competitive ability with other perennial grass plants. The contribution to total yield by three native seeded species (pink pappus, plains bristlegrass, and Arizona cottontop) was generally highest the first 2 years following treatment and declined as time passed. Plains bristlegrass completely disappeared in 4 years, probably from selective heavy grazing. Four-flower trichloris, a seeded native species, increased with time for both manipulation treatments, but grazing animals did not utilize this species as much as they did other species. It was observed that the order of utilization by cattle was buffelgrass > plains bristlegrass > cottontop and pink pappus > four-flower trichloris.

The percent herbage contributed by voluntary native nonseeded grass species was consistent for mechanical manipulation treatments over time. Seeding and mechanical brush manipulation did not result in a significant change in herbage contributed by the volunteer nonseeded native species; however, a shift in some species did occur.

Percent herbage contributed by volunteer nonseeded grass species in the undisturbed control decreased from 1973 to 1976. The decrease in these species was attributed to the ability of buffelgrass to successfully compete with native grasses.

Herbage constituted by forbs was high the first year for both mechanical manipulation treatments, but by the fourth year it was down to 3%. The control treatment averaged about 10% forb herbage production and was generally consistent over time. The invasion of forbs as occurs in secondary succession following mechanical treatment poses a problem the first year; however, with time, forb densities decrease.

The change in grass composition from native species to buffelgrass will occur when buffelgrass is seeded. Observations from this study indicated that buffelgrass is more preferred by cattle than native grasses and is grazed more readily. Moreover, its fast growth characteristics and rapid recovery following rainfall promotes its ability to predominate or invade. Buffelgrass should not be seeded where a diversity that includes native perennial grasses is desired.

Herbage production on the rangelands of the Rio Grande Plain can be increased by fertilizer application. In this study, 45 kg/ha N, applied in the fall significantly ($P<0.05$) increased herbage production following both mechanical manipulations as compared with the control. However, the increase was only for the season following application, and no effect was evident during the second season. Perhaps at higher rates of application, residual responses could be obtained, but this would depend on seasonal rainfall after application. Another alternative would be to reapply a smaller amount each year rather than to try to carry over residual effects.

Summary and Conclusions

Vegetation of much of south Texas rangelands has changed since domestic livestock were introduced some 100 or more years ago. Generally, the change has been characterized by a reduction in perennial grasses and an increase in woody plants and cacti.

Mechanical manipulation of brush followed by grass seeding decreased or retarded brush growth and increased forage production threefold to fourfold. However, the major portion of forage increase was attributed to an introduced perennial grass, buffelgrass. The success of buffelgrass seeding can be enhanced greatly by rootplowing to increase water infiltration. New seedings must be protected from domestic livestock grazing for at least one growing season, and longer periods are desirable.

Application of 45 kg/ha N increased both annual and perennial grass herbage production in the mechanical treatments, but showed no effect in production in the undisturbed control. However, the increase lasted only one season. The cost/benefit analysis for using small amounts of fertilizer annually to increase the rate of range improvement and to improve distribution of use needs to be evaluated.

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Effect of Grazing by Cattle on the Abundance of Grasshoppers on Fescue Grassland

N.D. HOLMES, D.S. SMITH, AND A. JOHNSTON

Abstract

Grasshoppers were collected annually from 1970 to 1976 in late August from experimental fields of fescue rangeland that had been grazed by cattle at four rates of intensity. Sixteen species of grasshoppers were found but only four species constituted 90% of the population. *Chorthippus longicornis, Melanoplus sanguinipes, Aeropedellus clavatus, Neopodismopsis abdominalis,* and *M. bivittatus* were more abundant on the lightly and moderately grazed fields, whereas *M. dawsoni, M. gladstoni* and *M. infantalis* were more abundant in the heavily and very heavily grazed fields. *Camnula pellucida* was randomly distributed among the four fields. Generally, more grasshoppers were collected from the heavily and very heavily grazed fields than from the lightly and moderately grazed fields.

The distribution and abundance of various species of grasshoppers are related to the composition and density of the vegetative cover on native grasslands (Anderson 1964). Therefore, changes in the vegetative cover should result in changes in grasshopper populations. It has been demonstrated that renovations of rangeland involving contour furrowing and scalping reduced the numbers of most species of grasshoppers in a test area (Hewitt and Rees 1974). Anderson (1964) has suggested that grazing practices may affect the abundance of grasshoppers, and Bird (1961) postulated that overgrazing by buffalo created an environment that favored outbreaks of grasshoppers in the plains area. A general review of the subject has been recently published by Hewitt (1977).

The study reported here was initiated to determine if different intensities of grazing affect the densities of various species of grasshoppers on native fescue rangeland. An experimental area in the foothills of southern Alberta on which controlled intensities of grazing by cattle had been applied for 19 years provided a unique opportunity for this work.

Materials and Methods

The study was done from 1970 to 1976 on four fields at the Stavely Range Research Substation located on a fescue grassland range 100 km northwest of Lethbridge, Alta.

Each of the fields had been grazed since 1951 at one of four intensities: light—0.8 ha/animal unit/month; moderate—0.6 ha/animal unit/month; heavy—0.4 ha/animal unit/month; and very heavy—0.2 ha/animal unit/month (Johnston et al. 1971). The grasshoppers on each of the four fields were sampled in late August each year with 100 sweeps of a standard insect net, except in 1974 and 1975 when 50 sweeps were taken. The samples, which were brought into the laboratory for identification and enumeration, are reported on the basis of 50 sweeps per field.

The relative frequencies of the components of the vegetation in the four fields and the yields of these components, which had been measured before the start of this experiment (Johnston et al. 1971), were measured again in 1977.

Results and Discussion

The progressive increases in rates of intensity of grazing progressively decreased the area covered by grasses, increased the area covered by forbs, but had no effect on the sedges among the four experimental fields. Very heavy grazing created a drier microclimate with increased soil temperature and decreased soil moisture (Johnston et al. 1971). Measurements in 1977 confirmed that the average percentage composition and basal area and yield of various components of the vegetation reflected the grazing treatments. The dominant grass, *Festuca scabrella* Torr., decreased as grazing intensity increased. Similarly, the amounts of grasses, forbs and shrubs, and litter decreased as intensity of grazing increased. Grazing produced a lower-growing type of cover that was less dense than on the lightly grazed fields. The total above-ground vegetal biomass was lowest on the very heavily grazed field; the lightly grazed field produced 1,671 kg/ha of vegetation and 1,864 kg/ha of litter compared to 82 kg/ha of vegetation and no litter from the very heavily grazed field.

Sixteen species of grasshoppers were found but only the most common are listed in Table 1. Other species found were *Encoptolophus sordidus* (Scudder), *Melanoplus bruneri* Scudder, *M. foedus* Scudder, *M. oregonensis* (Thomas), *Opeia obscura* (Thomas), *Psoleossa delicatula* (Scudder), and *Xanthippus* sp.

Of the four species that constituted 90% of the population, *Melanoplus dawsoni* was more prevalent every year on the heavily and very heavily grazed fields, whereas *Chorthippus longicornis*, every year, and *M. sanguinipes*, except in 1972, were more abundant on the lightly and moderately grazed fields (Table 1). *Camnula pellucida* appeared to be randomly distributed among the four fields.

The responses of the different species of grasshoppers to the changes in vegetative cover appear to be related to their food and

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Table 1. Mean numbers of grasshoppers per 50 sweeps on fields at Stavely Substation subjected to four rates of grazing, 1970-76.

Species of grasshopper	Intensity of grazing of field: Light	Moderate	Heavy	Very heavy	Mean
Melanoplus dawsoni (Scudder)	46.6	52.4	90.0	132.0	80.3
Chorthippus longicornis (Latr.)	61.9	47.0	40.6	23.0	43.1
Camnula pellucida (Scudder)	18.9	14.6	18.7	27.7	20.0
Melanoplus sanguinipes (F.)	14.0	9.0	1.7	6.1	7.7
M. gladstoni Scudder	2.9	3.4	4.6	8.4	4.8
M. bivittatus (Say)	3.0	4.7	2.1	2.3	3.0
Neopodismopsis abdominalis (Thomas)	4.9	2.0	3.0	1.0	2.7
M. infantalis Scudder	1.3	1.6	0.7	5.1	2.2
Aeropedellus clavatus (Thomas)	1.0	3.3	0.4	1.0	1.4
Total	154.5	138.0	161.8	206.6	

habitat preferences. *M. dawsoni* is primarily a forb feeder, *C. longicornis* feeds on grasses and sedges, *M. sanguinipes* is a mixed feeder with a preference for forbs, and *Camnula pellucida* is a grass and sedge feeder that readily eats forbs (Brooks 1958). Anderson (1964) found *M. dawsoni* to be most prevalent on fields with low percentage foliage cover and *C. pellucida* to be most abundant on fields with a 21−60% perennial grass cover.

Melanoplus gladstoni and *M. infantalis,* which were most prevalent on the heavily grazed field, are general mixed feeders (Brooks 1958). *M. gladstoni* was one of the few species found to be unaffected by scalping rangeland (Hewitt and Rees 1974) and *M. infantalis* occurred most frequently on sites with less than 20% foliage cover (Anderson 1964).

Neopodismopsis abdominalis was most abundant on the lightly grazed field and *Aeropedellus clavatus* was most abundant on the moderately grazed field. Both feed on grasses and sedges (Brooks 1958). *Melanoplus bivittatus,* which was also most abundant on the moderately grazed field although it was common on the other fields, is a general feeder that prefers forbs (Brooks 1958).

Despite the decreases in numbers of *C. longicornis* and *M. sanguinipes* caused by the heavier rates of grazing, the increases in numbers of *M. dawsoni* in particular were enough to produce higher total numbers of grasshoppers on the heavily and very heavily grazed fields than on the lightly and moderately grazed fields in 5 of the 7 years (Table 1). Similar results were obtained in studies in Oklahoma and Kansas where it was shown that grasshoppers were generally more abundant on heavily grazed pastures than on lightly grazed ones (Smith 1940; Campbell et al. 1974).

Increased intensity of grazing progressively reduced the amounts of vegetation available for consumption by grasshoppers. In the 1950-67 period, the cattle utilized 20, 50, 70, and 90% of the forage from the lightly, moderately, heavily, and very heavily grazed fields (Johnston et al. 1971). At the end of the growing season in 1977, the weights of vegetation, including litter left on the moderately, heavily, and very heavily grazed fields were 28.8, 18.5, and 2.4% of the left on the lightly grazed field. Thus, increased competition by grasshoppers for forage could result from increased grazing even if the numbers of grasshoppers remain constant or even decrease. Nerney (1958) has reported that a population of 15 grasshoppers/yd^2 (17.9/m^2) ate 20% of the herbage on a moderately grazed pasture and 70% of that on a heavily grazed one. As the decreased amounts of forage on the heavily and very heavily grazed fields at Stavely were combined with increased numbers of grasshoppers, it appears that the economic effects could have been compounded by the heavier rates of grazing.

Conclusions concerning the losses incurred, however, cannot be drawn from the present study, which was undertaken only to determine if grazing affected grasshopper populations. Such conclusions would require a detailed examination of the amounts and kinds of vegetation eaten by the species of grasshoppers involved as well as periodic samples taken during the growing season to account for early hatching species that may be absent after mid-July.

Conclusions

Changes in the microhabitat caused by varying intensities of grazing by cattle had major effects on the grasshopper population on a fescue rangeland. Increased intensity of grazing decreased the numbers of some species of grasshoppers, and increased the abundance of others. One species of grasshopper, which was apparently more widely adaptable than others, was unaffected. The change in the vegetative cover caused by the heaviest rates of grazing resulted in increased total numbers of grasshoppers in most years.

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Potential Evapotranspiration and Surface-mine Rehabilitation in the Powder River Basin Wyoming and Montana

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Abstract

Energy resource development in the Western United States must contend with the problem of water deficiency resulting from potential evapotranspiration rates which usually exceed precipitation rates. In this report the Blaney-Criddle method, with locally calibrated monthly natural vegetation coefficients, was used to estimate potential evapotranspiration (PET) for the Powder River Basin, Wyoming and Montana. In this area PET ranges from 15.02 inches per year to 26.76 inches. A radiation-based method for microclimatic adjustment of PET is presented. According to this procedure it might be expected that, for slopes of 20% inclination at 44° North latitude, annual PET is 17% less on northerly-facing slopes than a horizontal surface and 14% more on southerly-facing slopes.

The rehabilitation of disturbed lands must accompany energy resource development in the United States (U.S. Congress 1977). Erosion control is a primary goal of surface-mine rehabilitation because prolonged productivity of the land or aesthetic considerations are impossible if the soil is rapidly eroding. Erosion control is achieved through (1) proper surface contouring and (2) revegetation. The former is largely a mechanical exercise, while the latter is commonly a more difficult proposition in the Western United States, where much of the mineral and most of the coal reserves and resources lie within arid or semiarid climatic zones.

Discussions of mine-site rehabilitation potential typically include consideration of the climatic influences on revegetation. Frequently, however, evaluations of rehabilitation potential are based on incomplete information. A preoccupation with precipitation is often apparent (National Academy of Science and National Academy of Engineering 1974; Packer 1974), although the significance of precipitation lies in its relation to potential evapotranspiration (PET). Taken together, these two climate elements largely determine the amount of moisture available for plant use or, in arid and semiarid regions, the magnitude of water deficiency.

I submit that rehabilitation potential is inversely related to water deficiency. Therefore, PET data are necessary in order to evaluate the severity of drought, irrigation water requirements, and hence, rehabilitation potential. It is the purpose of this report to present estimates of PET for the Powder River Basi Wyoming and Montana, based on the Blaney-Criddle meth (1962), and utilizing crop coefficients for natural vegetation the Northern Great Plains. A radiation-based method for micr climatic adjustment of PET estimates is proposed.

Evapotranspiration, Vegetation Growth, and Rehabilitation

A brief discussion of evapotranspiration (ET) and its relati to vegetation growth illustrates the the significance of th parameter in rehabilitation studies and practice. ET is mai tained at the potential rate only as long as there is a plentifu nonlimiting supply of soil moisture. At some point during sc dehydration, ET falls below the potential rate. Chang (196 provides a summary of the controversy concerning the effect soil moisture tension on ET rates.

The assumption of nonlimiting soil moisture is rarely valid the Western United States. High mountain meadows an occasionally, valley floors, both with higher water tables ar subirrigated vegetation, are possible exceptions. In most case the concept of actual evapotranspiration (AET), resulting fro existing climatic and soil moisture conditions, is the appropria measure of surface water loss. Hanson (1973) developed model for estimating AET which includes a soil moistu parameter.

When AET is less than PET, plant productivity will be le than the potential maximum. Chang (1968) illustrates th generalized relation between yield and adequacy of wat application. Allison et al. (1958) show the relation between cr yields and water use for a number of crops grown in lysimeter

Current irrigation practices used in revegetation seem to b based on the relation between ET and soil moisture tensic proposed by Veihmeyer and Hendrickson (1955) and supporte by other researchers. According to their view, ET continues the potential rate up to the wilting point (15 bars) and fal sharply thereafter. However, work by Thornthwaite and Mathe (1955) indicated a linear inverse relation between ET and so moisture tension. Pierce (1958) concluded that ET continued the potential rate at low tension perhaps up to 0.4 bars and the rapidly decreased with increasing tension in curvilinear fashio If the relations proposed by either Thornthwaite and Mather Pierce are correct for species used in revegetation, then pla productivity is probably limited by the failure of curre practices to provide sufficient soil moisture to maintain ET the potential rate. Dwyer and DeGarmo (1970) found th production was greatest for selected desert shrubs and grasse

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with a field capacity soil-moisture level, and lowest at a moisture of one-third of field capacity for shrubs and at one-fourth of field capacity for grasses. However, water use per gram of dry matter produced (the measure of water-use efficiency) was highest at the field capacity soil-moisture level with the highest efficiencies of production occurring at one-third of field capacity. Under severe moisture stress (one-fourth field capacity), plants used more water and produced less dry matter. Since timely revegetation depends largely on plant productivity to produce a surface cover rather than efficiency of water use, it appears desirable to maintain soil moisture levels near field capacity, a condition allowing ET at the potential rate, at least until the plants have developed a significant root system. Unfortunately, in areas of extreme aridity, available water may be insufficient to maintain this level of soil moisture. In such cases, efficiency of water use gains importance. Plant survival, rather than biomass production, may be all that can be expected during some periods and effective rehabilitation will be delayed accordingly.

Irrigation and surface treatment techniques, employed to improve the probability of successful revegetation in surface-mined areas with extremely low and erratic precipitation, affect ET. The results of several irrigation experiments were reported by Aldon and Springfield (1977). As a consequence of irrigation practices, the normal irrigation applications are usually insufficient to maintain soil moisture levels near field capacity. Indeed, in one area, water was applied when vegetation showed visible signs of stress. Therefore, the amount of water evapotranspired was somewhere between the potential quantity and that which would have been AET under natural conditions. PET rates may be reached for short periods following irrigation applications or precipitation events.

Mechanical and chemical surface treatment techniques also alter the natural water balance of spoils piles undergoing rehabilitation. Hodder (1977) describes the effects of mulching, cultivation, top-soiling, deep chiseling, gouging, off-set listering, and excavation of doser basins. Aldon and Springfield (1977) describe the effects of water harvesting techniques utilizing the application of paraffin, silicone, or black polyethylene to the surface. The usual purpose of mechanical or chemical treatments is to increase the available soil moisture for plant use through a reduction of runoff and ET, an increase in infiltration, or by concentrating available water into a smaller area. The net effect of these practices is to increase the proportion of available moisture transpired to that evaporated from the soil surface. Additionally, AET from a treated surface will exceed that from an untreated surface because of the increased amount of soil moisture made available by these techniques. Experimental field plots are likely to be the only approach to measuring AET under the complex artificial conditions of rehabilitation.

Estimating Potential Evapotranspiration

Three factors favored the use of the Blaney-Criddle method for PET estimation: (1) availability of data, (2) effectiveness of these method when crop coefficients are locally calibrated, and (3) widespread acceptance of this method. The Blaney-Criddle method requires only mean monthly temperature, available at a large number of cooperative climate stations in the Powder River Basin, and station latitude as inputs. Burman et al. (1975) concluded that the Blaney-Criddle method, utilizing locally calibrated crop coefficients, appeared to be the most satisfactory of the 15 methods compared. Data for crop coefficient calibration were provided for use in the present study by Lauenroth and Sims (1976) and through personal communication; their use will be discussed in a subsequent section. Finally, the Blaney-Criddle method has provided estimates of PET in a variety of studies differing in purpose. The U.S.D.A. Soil Conservation Service (1970) uses this method as a part of its model for estimating irrigation water requirements. Burman, et al. (1975) acknowledge its widespread acceptance in water right transfer proceedings. Further, they note that the legal profession, lay personnel, and engineers not familiar with other methods understand the Blaney-Criddle method. This may be an important consideration when dealing with surface-mine revegetation and rehabilitation.

The Blaney-Criddle method estimates monthly consumptive use of water according to the formula:

$$u=kf \qquad (1)$$

where:

u=monthly consumptive use PET in inches
k=monthly crop coefficient
$f=\dfrac{t\times p}{100}$ = monthly consumptive-use factor
t=mean monthly temperature, °F
p=monthly percentage of daytime hours of the year (derived from tables and based on latitude)

The values derived for consumptive use by this method may be considered estimates of PET because the model assumes a nonlimiting water supply. Most investigators, including Cruff and Thompson (1967); Burman, et al. (1975); and Jensen, et al. (1973), have used the estimates in this way. Crop coefficients (k) have been experimentally determined for a variety of agricultural crops. In these studies, consumptive use was usually measured by lysimeter; and these values, together with those for f, were inserted into equation (1) such that $k=u/f$. The same procedure was used for determining monthly values for k in this research.

Crop Coefficient Calibration

The crop coefficients used for estimating PET in surface-mined areas should reflect the consumptive use characteristics of the vegetation species used in rehabilitation. Two strategies are possible for coefficient calibration: (1) use of consumptive-use measurements for revegetation species, such as western wheatgrass (*Agropyron smithii*); or (2) use of measurements for natural vegetation in the area. The latter strategy is based on the assumption that the most successful species to be used in revegetation will have consumptive-use characteristics similar to the species indigenous to the area. Availability of data will likely determine which of these strategies to use in practice.

PET estimates were made by Lauenroth and Sims (1976) using the water balance method at the Pawnee site of the U.S. International Biological Program Grassland Biome from 1971-1973. The natural vegetation at this site, east of Fort Collins, Colorado, is characteristic of a large portion of the shortgrass prairie and consists of blue grama grass (*Bouteloua gracilis*), fringed sagewort (*Artemisia frigida*), scarlet globe mallow (*Sphaeralcea coccinea*), plains pricklypear (*Opuntia polyacantha*), broom snakeweed (*Gutierrezia sarothrae*), and needleleaf sedge (*Carex eleocharis*). Lauenroth and Sims (1976) comment: "If the agreement between the data predicted by Penman's model and those arrived at by the water balance data from the water plus nitrogen treatment is accepted as evidence of the credibility of both, they may then be accepted as defining a range for potential evapotranspiration in the short-grass prairie of northeastern Colorado." Nitrogen treatment

Table 1. Blaney-Criddle crop coefficients for natural vegetation in the Northern Great Plains.

	1971	1972	1973	*k**
April		0.69	0.38	0.54
May	1.18	0.52	0.48	0.73
June	1.18	0.78	1.06	1.01
July	0.92	1.10	0.92	0.98
August	0.94	0.81	0.84	0.86
September	0.74	0.38	0.83	0.65

* Average monthly coefficient.

may enhance the utility of these data because rehabilitation sites are frequently fertilized.[1]

The consumptive-use data described above, together with the mean monthly temperature data obtained, were used to derive monthly crop coefficients during the growing season from 1971 to 1973 (Table 1). The variation of monthly crop coefficients from year to year reflects specific climate conditions prevalent during that period. For example, there were frequent thunderstorms during the first 2 weeks of June 1972, according to Dr. Lauenroth (personal communication, 1976). Consequently, the values in Table 1 suggest a range; all were included in the computation of the average coefficient because they are indicative of natural conditions. Figure 1 is a graphic portrayal of the average coefficients. The form of this curve is similar to that for other crops (U.S.D.A., Soil Conservation Service 1970).

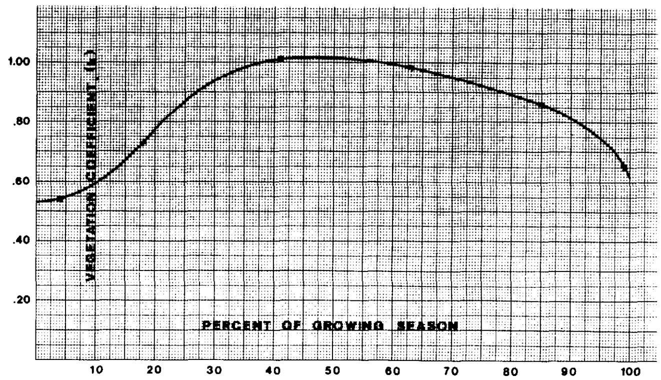

Fig. 1. *Average vegetation coefficients for natural vegetation of shortgrass prairie in Northern Great Plains.*

Potential Evapotranspiration in the Powder River Basin

Average growing-season PET was estimated for 63 climate stations in Powder River Basin using the Blaney-Criddle method with the average crop coefficients contained in Table 1 and mean and monthly temperature data for the period 1965-1974. The growing season was defined as the frost-free period, extending from the mean date of last spring frost to the mean date of the first autumn forest as advocated by Critchfield (1966) and supported by the U.S.D.A., Soil Conservation Service (1970). Soil Conservation Service program TR-21-V3 was used for the actual computations.

Figure 2 (Toy and Munson 1978) was produced by interpolating isopleths between the derived station values. This figure shows the variation in PET for natural vegetation throughout the Powder River Basin. Other things being equal, this is the amount of water required to sustain vigorous plant growth for revegetation of surface-mined areas during the entire growing season. Even in this rather geographically limited area, there is a PET range of 11.74 inches with Miles City, Montana, capable of losing 26.76 inches of water and Kirby 1S, Montana, losing 15.02 inches. The data contained in Figure 2 serve as a useful baseline for environmental impact statement preparation. Naturally, site-specific information must be collected on location; however, time constraints frequently preclude the collection of these data.

Topographic Influences on Potential Evapotranspiration

In semiarid regions natural vegetation development on hillslopes of southerly aspects tends to be more xeric than on northerly aspects. For the Cheyenne River Basin in east-central Wyoming, Hadley (1962) found that plant cover on southerly-facing slopes is only 28% of that occuring on northerly-facing slopes. This difference is usually attributed to greater moisture deficiencies on slopes of southerly aspect. This moisture deficiency is due to the higher rates of solar insolation received throughout the year resulting in higher rates of PET.

Chang (1968) and Jensen et al. (1973) note that the rate of PET is largely determined by net radiation in the absence of significant advected energy. Net radiation is defined as the difference between the incoming and outgoing radiative fluxes, both short-wave and long-wave. Unfortunately, net radiation data are collected at very few locales within the United States. Based on 14 stations throughout the world, Davies (1967) has found that net radiation can be estimated from total solar radiation (r=0.99):

$$Rn=0.617Q-24 \qquad (2)$$

Rn=net radiation
Q =total solar radiation

Frank and Lee (1966) suggest that in the net radiation balance, diffuse sky radiation, thermal atmospheric radiation, reflected and thermal terrestial radiation components are largely self-cancelling over extended periods of time; and, hence, net radiation is proportional to direct beam solar radiation. Also noteworthy in this context is the comment by Chang (1968) that direct insolation is a function of both aspect and slope inclination, while diffuse radiation, being essentially uniform in all aspects, is affected only by the latter; a 10° northerly-facing slope receives just as much diffuse sky radiation as a 10° southerly-facing slope.

In the absence of collected radiation data for hillslopes of various inclinations and aspects, an indirect, if nonrigorous, method must be devised for adjusting horizontal surface PET estimates for topographic influences. If the following assumptions can be accepted as essentially valid for a period of several months' duration, then the data provided by Frank and Lee (1966) and the formulas devised by Davis (1967) can be used to make PET adjustments. The assumptions on which the procedure depends are: (1) PET is proportional to net radiation, (2) net radiation is proportional to direct solar beam radiation, (3) diffuse sky radiation is constant for slopes of the same inclination, and (4) the effect of the atmosphere in reducing potential direct beam radiation to that actually received at the surface is essentially constant for slopes of the same inclination but different aspects.

Table 2 shows the comparison of net radiation received on a northerly- and southerly-facing slope, both of 20% inclination, at 44° North latitude. These values were computed using potential direct beam radiation values provided by Frank and Lee (1966) with the Davies equation used to estimate net radiation values. Three time intervals are considered: (1) the full

[1] A word of caution to those using the data presented by Lauenroth and Sims (1976): There are errors in Table 1 of that report, and Figures 5 and 6 are switched (personal communication with Dr. Lauenroth, March 4, 1977).

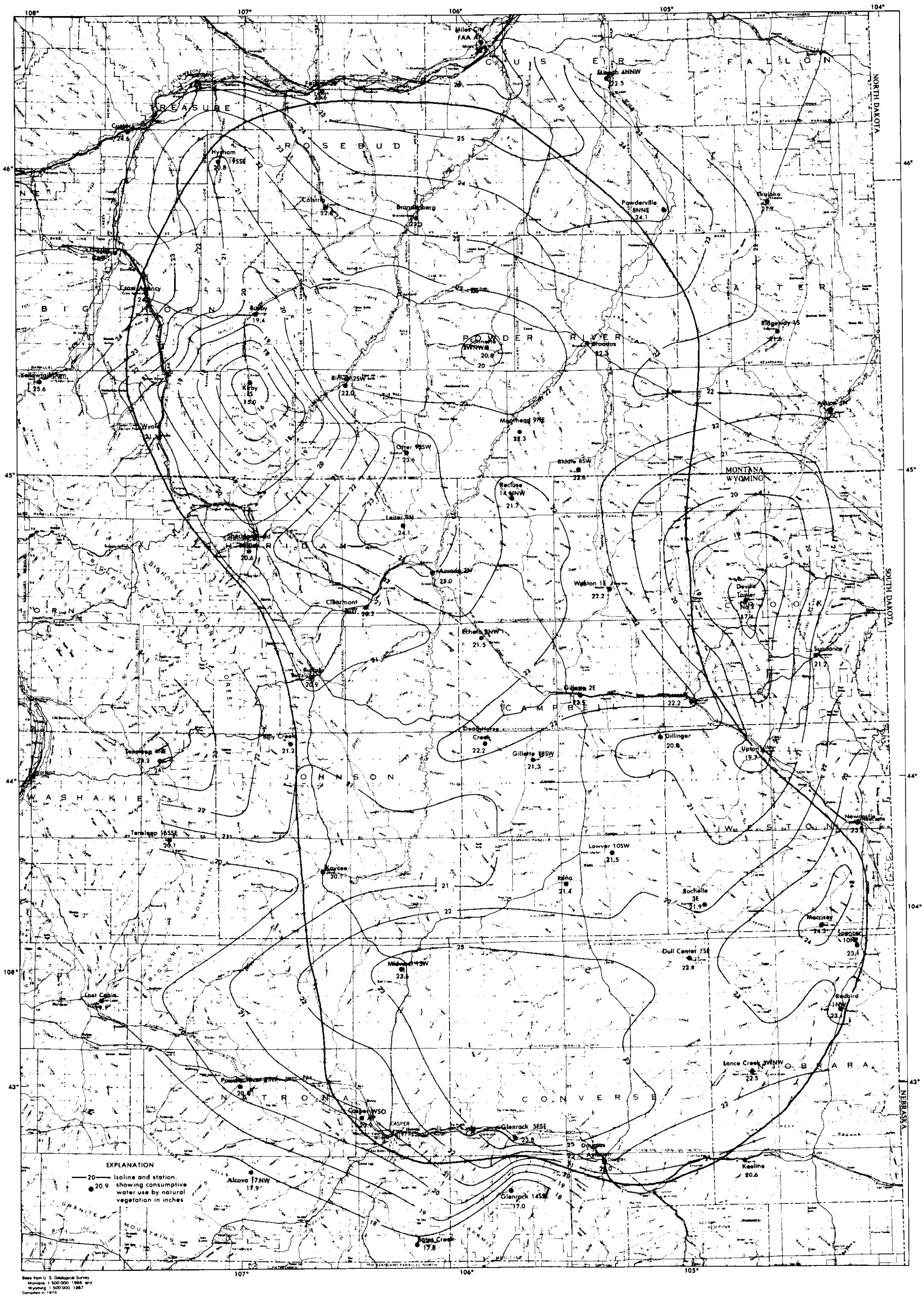

Fig. 2. *Isopleth map of consumptive water use in Powder River basin.*

year, (2) the pre-growing season period from the winter solstice to the beginning of the growing season, and (3) the growing season period. For the annual period, the northerly-facing slope receives 83% of the radiation received on a horizontal surface, while the southerly-facing slope receives 114% of that received on a horizontal surface. For the pre-growing season period, the northerly-facing slope receives 79% of the radiation received on a horizontal surface, while the southerly-facing slope receives 118% of that received on a horizontal surface. For the growing season, the northerly-facing slope receives 94% of the radiation received on a horizontal surface, while the southerly-facing slope receives 103% of that received on a horizontal surface. These ratios can be used to adjust measured solar radiation data, where such information exists, for use in radiation-based methods of estimating PET (Wymore, 1974), or adjusting PET estimates derived by other methodologies. In other words, for slopes of 20% inclination at 44° North latitude, it might be expected that PET is 17% less on northerly-facing

Table 2. Variation in energy receipt with slope aspect (20% inclination, 44° N. lat.).

	North-facing (N)	Horizontal (H)	South-facing (S)	N/H	S/H	N/S
Potential direct beam radiation (ly)[1]						
Pre-growing season (12/22-5/27)	73,931	94,094	111,367	0.79	1.18	0.66
Growing season (5/28-9/17)	98,868	105,172	107,932	0.94	1.03	0.92
Full year	199,035	240,588	274,472	0.83	1.14	0.73
Net radiation (ly)[2]						
Pre-growing season (12/22-5/27)	45,591	58,032	68,689	0.79	1.18	0.66
Growing season (5/28-9/17)	60,978	64,867	66,570	0.94	1.03	0.92
Full year	122,781	148,419	169,325	0.83	1.14	0.73

[1] Frank and Lee (1966).
[2] Davies (1967).

slopes than on a horizontal surface and 14% more on southerly-facing slopes for the annual period. Similar inferences can be made for the other time periods. The estimates of PET for horizontal surfaces provide adequate average estimates considering the accuracy of the estimating procedures themselves.

While the foregoing may be acceptable in theory, reality is, of course, more complex. It seems unlikely that the disparity in plant cover can be adequately explained by the difference (N/S=0.92, Table 2) in energy received during the growing season on northerly- and southerly-facing slopes. However, the difference (N/S=0.66, Table 2) in energy received during the pregrowing season period may well be significant, especially in areas where available moisture is near the minimum requirement for plant survival and development. Higher insolation rates on southerly-facing slopes prior to the commencement of the growing season result in increased winter evaporation losses, and reduced water supplies available for soil water recharge from spring snowmelt (Wymore 1974). Further, Wymore (1974) suggests that the growing season is initiated much sooner on slopes of southerly aspect, and Leopold (1974) notes that growing season length is the most important climatic characteristic governing water needs of vegetation. Exposure to prevailing winds also affects the amount of snow cover on the surface and hence soil moisture recharge in the spring. Observed differences in vegetation density along snow fences together with those on lee and windward slopes verify the significance of this factor. On-site experimentation and experience are necessary to measure precisely the influence of topography, although approximations and expectations can be obtained through the procedure described herein.

Discussion

PET is a frequently neglected component of the hydrologic system affecting surface-mine rehabilitation in the arid and semi-arid Western United States. Estimation of this component, however, is a prerequisite to an evaluation of the magnitude of water deficiency. While recognizing the importance of other environmental factors affecting vegetation growth, it is my contention that rehabilitation potential is inversely related to water deficiency. Indeed, the severity of drought may be a paramount consideration in the design of a rehabilitation program.

The information and procedures contained in this report can be used, together with precipitation records, to estimate irrigation water requirements. Irrigation during the initial period of rehabilitation (perhaps a year or two) can reduce the risk of revegetation failure due to insufficient precipitation. In some areas it may be essential; in others, merely insurance. The amount of water used for irrigation in most areas is likely to be a small percentage of that used solely for dust control. The cost of irrigation equipment may be amortized over an extended time period and, in the long run, may prove more economical than periodic retreatment of areas due to revegetation failure. According to Harley Meuret (personal communication, June 26, 1978), reclamation specialist at the Jim Bridger Mine in southwestern Wyoming, the cost of one reseeding is approximately equal to the cost of irrigation for the first season of reclamation.

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The Economics of Sheep Predation in Southwestern Utah

R.G. TAYLOR, JOHN P. WORKMAN, AND JAMES E. BOWNS

Abstract

Ten sheep ranches in southwestern Utah were chosen for a verification study of sheep losses during 1972-1975. Using the ratio of verified predator kills to total lamb carcasses discovered, total lamb loss to predators was estimated. Predation accounted for 5.8% of total lambs docked or 62% of the total lamb loss. Coyotes made 94% of all predator kills. For the 10 herds (1972-1974) direct income loss due to lamb predation averaged $2,800 per herd; for a three-herd subsample (1972-1975) direct income loss averaged $3,500 per herd. Applying our study rate of predation to the entire Southwest region of Utah gave an estimate of 14,900 lambs killed by predators and a direct income loss of $419,000. In addition, the region suffered indirect or multiplier losses of $1,166,000 to $1,816,000 during the 4 years studied. Further data needs in predation economics could be achieved by integrating predation loss, predator population, and predator control data into a standard production function model.

Recent profit reductions have resulted in 10% annual decreases in Utah's sheep numbers (Statistical Reporting Service 1976) and have increased the sheepman's incentive to prevent livestock predation losses. Simultaneously, predator control has become increasingly complex. Early predator control research was aimed primarily at discovering methods of eradicating coyotes, the most troublesome predator (Bailey 1904, 1908). More recently, financial relief through economically efficient predator control has come into increased conflict with interests promoting esthetic, recreational, and ecological values associated with a viable predator population.

To define the magnitude of the predation problem and to provide a data base for an economic analysis, a verification study of sheep loss was initiated in March 1972 in the Cedar City area of Utah (Bowns et al. 1973a, 1973b; Davenport et al. 1973). A study requiring examination of each sheep carcass was chosen over a rancher survey questionnaire to eliminate possible reporting bias. In cooperation with the Cedar City Livestock Association and the Southern Utah State College (SUSC) Experimental Farm, 10 sheep ranches were selected as sample operations to form the data base for the initial 3-year phase. In the fourth year, 1975, the sample was reduced to three herds. All sample herds were migratory range sheep operations, typical of commercial sheep ranches throughout the Intermountain states. Most herds winter on desert ranges near the Nevada border west of Cedar City and after shed lambing in the spring are trucked or trailed to high elevation summer ranges east of Cedar City.

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Methods

Cooperating ranchers and herders were asked to promptly report all dead and injured sheep so researchers could make an immediate examination to ascertain cause of death or injury. As the study proceeded, researchers increasingly relied on periodic checks of each pasture to locate lamb carcasses. Ranchers continued to report sheep losses and provide necessary lamb counts.

Total lamb loss was determined from the ranchers' inventory of lambs at docking, during trucking or trailing between the spring and summer range, and at weaning or marketing. The difference between docking and trucking or trailing counts gave the total spring lamb loss and the difference between trucking or trailing counts and weaning count gave the total summer lamb loss. Predation losses of age classes other than lambs were minor so inventory efforts were concentrated on lambs. Predator kills were verified according to strict criteria by experienced study personnel (Bowns 1976) and photographically documented.

If predation was not evident in the necropsy a lamb was classified as dying from natural causes. This statistic does not include natural pre-docking losses that occurred up to approximately 12 days after birth. All lamb carcasses were classified as (1) predator kills, (2) natural death, or (3) unknown cause of death. As the study progressed, researchers became more proficient in distinguishing between predatory and natural deaths. In 1973 the cause of death in 16% of lamb carcasses could not be diagnosed. In subsequent years 1% or less were listed as dying from unknown causes.

Despite the coordinated efforts of ranchers and researchers, only 36% of the total lamb losses in the initial study year were discovered

Table 1. Percentage of examined lamb carcasses verified as predator losses in herds 1, 3 and 5, southwestern Utah, 1972-75.

Herd	1975		1972-74 Mean	
	Spring	Summer	Spring	Summer
1	0	85.7	0.6	86.9
3	20.0	62.5	43.7	69.9
5	58.7	92.7	47.0	89.4
Mean[1]	26.2	80.3	30.4	82.1

[1] Paired t test between spring 1975 vs. spring 1972-1974 and summer 1975 vs. summer 1972-1974 were insignificant at .05 level.

and examined by the researchers. The remaining carcasses were obscured by dense vegetation and scattered over such a vast area that intensive searches were impractical. In subsequent years, researchers became increasingly successful at finding lamb carcasses by searching bedgrounds, dry washes, ravines, specific drainages and particular pastures more frequently. Lamb carcasses discovered increased to 41% in 1973 and 57% in 1974. In 1975 the sample herds were reduced from 10 to 3 so search efforts could be concentrated. With the intensive sample of 3 herds, 89% of the total missing lambs were discovered and examined.

The percent of verified predator kills represents only the minimum predation loss (Table 1). To accurately assess the full magnitude and resulting economic impact of predator losses the number of undiscovered predator kills had to be estimated. The carcasses found by researchers were assumed to be a random sample of total lamb losses. Thus the proportion of predator kills among those carcasses examined was assumed to be the same as among the undiscovered missing lambs. Calculation of the ratio of *verified* predator losses to total examined lamb losses and expansion of that proportion to the unaccounted for lamb losses (total missing lambs minus examined carcasses) gave the *estimated* predator lamb losses. Estimated predator loss was then added to verified predator loss, yielding a total predator lamb loss (Table 2).

Table 2. Total predator lamb losses as a percentage of total lamb losses, southwestern Utah, 1972-75.

Year	Herds 1-10	Herds 1, 3 and 5
1972	72.8	72.1
1973	53.2	50.5
1974	59.2	63.4
1975	No Data	49.2

Separate ratios were calculated for each year, season, and herd. Average ratios were then calculated for each herd for each season. This approach gave an unbiased estimated predator loss, whereas a verified predator loss ratio obtained by simply summing verified predator losses for all herds in the aggregate would have weighted the ratio in favor of the years in which high predator losses occurred.

The validity of this statistical inference is confirmed by comparing the predator loss ratios for herds 1, 3, and 5 during the final study year (1975) with those of the first 3 years of the study (Table 1). If the underlying premise was incorrect, the ratios would have reflected a declining or increasing proportion of predator kills as the proportion of observed carcasses increased. Instead, the ratio of verified predator kills to total loss remained essentially constant throughout the study even though the percentage of lamb losses examined was 54% higher during 1975 than during the first year.

The difference between *total* predator lamb losses and *verified* predator kills is substantial. Table 3 reveals the relative disparity between verified and total predator kills. All conclusions in this study are based upon *total* predator lamb losses.

Results and Discussion

Coyotes were responsible for all verified predation losses in 1972, 89% of the verified loss in 1973, 94% in 1974, and 92% in 1975. Bears, cougars, domestic dogs, and pigs inflicted the remaining predation losses. Invariably, coyotes selected lambs over other age classes of sheep. Only 17 ewes were verified as predator kills during the spring and summer seasons in 4 years of study. Therefore, spring and summer sheep depredation in southwestern Utah is predominantly coyote predation on lambs.

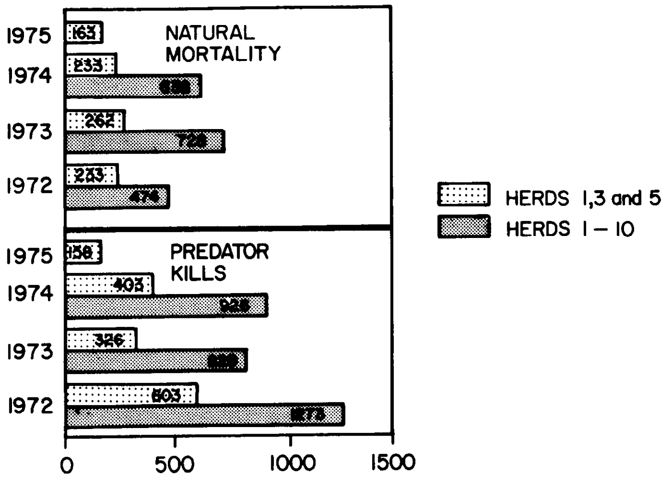

Fig. 1. *Natural mortality and total predator kills incurred by herds 1,3, and 5, 1972-75, and herds 1-10, 1972-74.*

During 3 years of study, predator lamb losses in herds 1-10 averaged 1,009 or 62% of the 1,623 mean total lamb loss. In herds 1, 3, and 5, which were studied for 4 years, total lamb loss averaged 584 with an average of 373 lambs (63%) destroyed by predators. Apparent from the annual losses shown in Figure 1 and corroborated by annual percentages of predation in Table 2, coyotes inflicted a majority (61%) of the total lamb loss. Also evident from comparison of Figure 1 and Table 2, greater total

Table 3. Total predator losses and verified predator losses as a percentage of lambs docked, southwestern Utah, 1972-75.

Year	Season	Herds 1-10		Herds 1, 3 and 5	
		Total predator loss	Verified predator loss	Total predator loss	Verified predator loss
1972	Spring	0.75	0.48	0.87	0.68
	Summer	6.21	1.25	7.54	0.32
1973	Spring	0.56	0.51	0.77	0.78
	Summer	4.14	0.97	3.77	1.96
1974	Spring	0.86	0.69	0.91	0.69
	Summer	4.96	1.87	4.34	1.35
1975	Spring	No Data	No Data	0.95	0.65
	Summer	No Data	No Data	1.94	1.35
Mean	Spring	0.72	0.56	0.88	0.70
	Summer	5.19	1.36	4.40	1.25

losses corresponded to higher predation losses and vice-versa. Figure 1 clearly shows that annual natural mortality is much more static than losses inflicted by predators. Therefore, not only did predators inflict a majority of the total lamb loss, but most of the escalation in total lamb losses can be attributed to predators.

During the spring, lamb depredation remained almost constant, while mortality from natural causes (which constituted the majority of the total spring lamb loss) fluctuated widely. However, during the summer almost the entire lamb loss was due to predation, while natural causes were minimal and quite static (Fig. 1). Seasonal disparity in natural mortality was anticipated. Several studies (Safford and Haversland 1960; Venkatachalam et al. 1949), including research with the SUSC experimental herd (Matthews and Ogden 1957), have described susceptibility of preweaning lambs to high incidence of pneumonia, malnutrition, infection, etc., during the first 5 to 7 weeks after birth. By the time the summer trucking or trailing count was taken, most natural mortality had already occurred.

The reason for the difference between the spring and summer predation loss was not as apparent. Predator losses in the spring were consistently lower than during the summer. In herds 1, 3, and 5 for example, spring predator loss differed by only five lambs from an average predation loss of 55 lambs during 4 years of study. Summer predator losses for these same herds varied from 2 to 10 times as much (Fig. 2). The smaller predator losses on spring ranges suggest that coyote deterrents such as shed lambing and nightly impoundment with the presence of a herder (infeasible on summer ranges) have successfully reduced predation to the minimum feasible level, despite apparently greater resident coyote density on the spring range.

The relative magnitude of predator losses was computed on the basis of lambs docked, since the docking count was the first taken. During the entire study, 5.8% of the lambs docked were killed by predators. Individual herd predator losses varied from 0.2 to 11.3% in the summer and from 0 to 3.5% in the spring. The rate of predation in southwest Utah is remarkably similar to rancher surveys of predation losses taken throughout the West, including (1) Nielsen and Curle (1970), who reported 61 lambs and ewes lost per 1,000 head of sheep in Utah; (2) Early et al. (1974), who reported 38-40 lambs lost per 1,000 head of lambs and 26-28 ewes lost per 1,000 head of ewes in Idaho; and (3) Reynolds and Gustad (1971), who reported an average predation rate in four Western states of 5.3%. Percentages of verified predation in Table 3 vary from 0.48 to 1.87%, considerably less than the 4% rate of verified predation compiled in Nevada (Klebenow and McAdoo 1976). However, we believe that an intensive sample with constant surveillance as in the Nevada study would have caused our verified predator loss to approach the total predator loss.

The herds selected in the sample were assumed to provide a representative sample of predation rates throughout much of the state of Utah. Yet differences in the level of predation losses were evident between seasonal ranges and between herds sampled, indicating a complex aggregation of management and environmental interactions unique to each herd on each seasonal range (Taylor 1977). Therefore, any geographical delineation of a homogeneous population of sheep herds is arbitrary—a compromise between limiting study results strictly to the study area or a statewide expansion, which would not be entirely warranted due to the small number and regional concentration of the sample herds. The population represented by the study was defined as southwestern Utah, including seven counties (Beaver, Garfield, Iron, Kane, Piute, Washington, and Wayne) which adjoined or were included in the study area. The ten representative ranches comprise 4.5% of the sheep ranches in that region (U.S. Department of Commerce 1977).

To estimate regional lamb losses (Table 4), the sample herd predation rate was expanded to the number of lambs docked region-wide (Statistical Reporting Service 1976). Since county data were unavailable, the number of lambs docked in the seven-county area was calculated by prorating the state sheep inventory (U.S. Department of Commerce 1977). In the seven-county region, an estimated 14,855 lambs were killed by

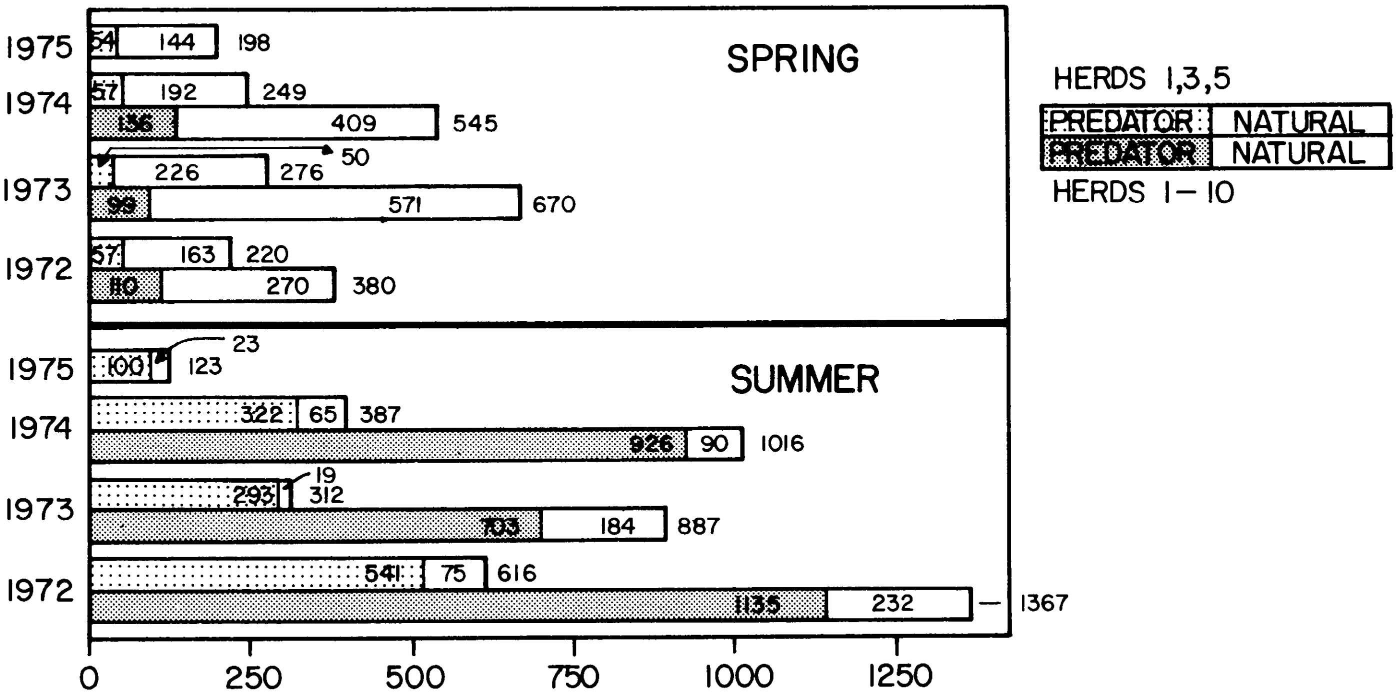

Fig. 2. *Total predator kills and natural mortality during spring and summer in herds 1,3,5, 1972-75, and in herds 1-10, 1972-74.*

Table 4. Computation of predator lamb losses in southwestern Utah, 1972-75.

Year	Lambs saved statewide[1] (1,000 lambs)		Rate of predation[2]		Regional proration[3]		Predator lamb loss in Southwestern Utah
1972	713	×	6.955	×	.1165	=	5,777
1973	635	×	4,699	×	.1165	=	3,476
1974	578	×	5.814	×	.1165	=	3,916
1975	502	×	2.886	×	.1165	=	1,688
Total							14,357

[1] Statistical Reporting Service (1976) data comparable to lambs docked.
[2] Number of lambs killed per 100 lambs docked.
[3] U.S. Department of Commerce 1977.

predators during the period 1972-1975, an average annual loss of 3,774 lambs (Table 4). Expansion of sample data to the entire state of Utah yielded a statewide predation loss of 127,521 lambs during the period studied.

Direct income loss due to lamb predation was calculated by multiplying the number of lambs destroyed times the average lamb value. Ideally, determination of the exact value of each lamb would require that any additional variable costs that would have been incurred after death of the lamb be subtracted from the market price. But since virtually all significant expenditures for lamb production are fixed in a lamb at birth, the average value of a predator kill would approximate the full fall market price. Thus average value was estimated by multiplying the price per hundredweight of Utah lambs (Statistical Reporting Service 1976) by 88 pounds, the average fall market weight of Utah range lambs (Goodsell and Belfield 1973). Study observations of coyote kills indicate that the average market weight may be conservative since coyotes appear to select larger than average lambs.

The direct income loss suffered by ranches 1-10 was estimated at $82,741 during the period 1972-1974 (Table 5). During the same period ranches 1,3, and 5 lost $41,913. This is an average annual loss per ranch of $2,758 and $3,493 for herds 1-10 and herds 1,3, and 5, respectively. Regional direct income losses were estimated at $419,323 for the 4 study years, an average annual loss of $1,897 for each of the 221 sheep ranches in southwestern Utah with sales greater than $2,500 (U.S. Department of Commerce 1977). Statewide predator losses were estimated at 3.6 million dollars for the same 4 years. As an indication of the severity of the impact of this loss on Utah's sheep industry, gross income for lamb and sheep sales in 1975 totaled 17.6 million dollars (Statistical Reporting Service 1976).

An expansion or contraction of one economic sector brings secondary changes in expenditures for inputs resulting in a decreased level of economic activity in other sectors of the economy. Hence, income losses resulting from predatory lamb losses reduce expenditures in the livestock sector and these "multiplier" effects reduce income of all other sectors of southwestern Utah's economy. Two such multipliers—a type I multiplier, which includes direct and indirect payments, and more comprehensive type II multiplier, which includes induced payments as well as direct and indirect payments—have been calculated for Utah's economy (Bradley 1967). The type I livestock multiplier of 2.781 and the type II livestock multiplier of 4.33 both ranked second compared to multipliers for 39 defined sectors in the state's economy. Applying these multipliers to estimates of annual direct income loss, the detrimental impact of predation lamb losses on the economy of southwestern Utah is shown in Table 5. During the 4 years studied, type I indirect income losses were $1,166,000 and type II indirect losses totaled $1,816,000.

It should be noted that total costs of coyote predation are composed of two parts: (1) the value of sheep that are destroyed by coyotes and (2) the costs incurred in attempting to control or deter coyote predation. Therefore, estimates in Table 5 of direct and indirect foregone income understate the total costs of predation by the amount ranchers spent on coyote control.

A final recommendation made by the historic Leopold Committee (1964) was that predator control programs be subjected to benefit-costs analysis. Cain et al. (1972) reiterated:

> Although the need for such economic studies was given high priority in the Leopold study, today, nearly eight years later, very little progress has been made in this direction. . .A review of costs and damage data available in 1971 reveals that the same state of affairs existed in 1964.

Studies in predation economics have traditionally been limited to estimates of depredation magnitude and assessment of damage. Focus should now shift to estimating the optimum rates of control and the coyote population density which is socially, economically, and ecologically acceptable. In economic studies of pesticide usage, production function models have provided a conceptual framework from which public policy has been examined (Headley and Lewis 1967; Economic Research Service 1971). Applied to predator control, a production function is the physical relationship between maximum obtainable lamb crop and successive increments of coyote control employed (Fig. 3). The level of coyote control and deterrent utilized throughout the current production cycle, plus residual control from previous years, are correlated with the resulting fall lamb crop. As the function approaches zero control, sample points

Table 5. Direct and indirect income loss of herds 1-10, herds 1,3, and 5, and for southwestern Utah, 1972-75.

Year	Lamb value per head (dollars)	Direct income loss: Herds 1-10	Direct income loss: Herds 1,3, and 5	Direct income loss: S.W. Utah	Indirect income loss S.W. Utah: Type I Multiplier	Indirect income loss S.W. Utah: Type II Multiplier
1972	24.38	31	15	141	392	609
1973	28.07	23	9	98	271	422
1974	30.71	28	12	120	334	520
1975	35.99	No Data	6	61	169	263
Total[1]		83	42	419	1,166	1,816

[1] Discrepency in column totals due to rounding.

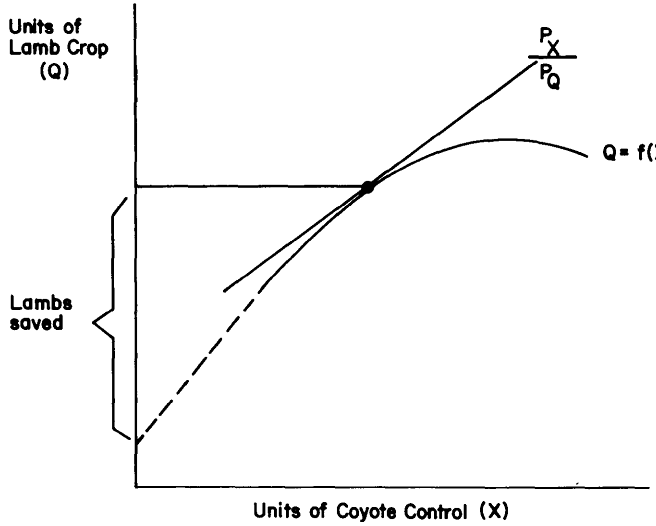

Fig. 3. *Hypothetical production function, f(X), with coyote control, X, the single input and lamb crop, Q, the output.*

will be absent because invariably some government or private control is practiced in any sheep producing area. Extrapolation of the function to the ordinate intercept (dashed line in Fig. 3) estimates the lamb crop in the absence of predator control—a figure which researchers have previously tried to calculate by studying comparable areas with and without coyote control (Munoz 1976; DeLorenzo and Howard 1975). Present value of the lambs saved from predators (total lamb crop minus estimated lamb crop without control) divided by the corresponding present value of predator control expenditures is the benefit-cost ratio measuring efficiency of the control program. The optimum control level is where the production function is tangent to the price line P_x/P_q in Figure 3, where P_x is the price (cost) of a unit of coyote control and P_q is the price (return of a unit of lamb production. At the optimum level, the last dollar spent on coyote control or deterent would return a dollar in additional lamb revenue. Knowledge of the optimum level would allow control expenditures in excess of optimum to be reduced and inadequate programs to be bolstered. Any deviations in coyote control or lamb crop from the optimum for social or environmental reasons could then be assessed in terms of trade-offs between lamb production and coyote populations.

Summary and Conclusions

This study was undertaken to assess lamb losses to predators and resulting economic losses in southwestern Utah. All field data collected from 10 sample herds pertain to lamb losses that occurred on spring and summer ranges between docking and marketing. Field work resulted in estimates of (1) total lamb loss, (2) verified predator kills, and (3) natural mortality. Since the verified predation kills represent only the minimum predation loss, the percentage predation of discovered carcasses were expanded to undiscovered lambs. The most serious predation occurred on summer ranges where intensive coyote deterrent isn't feasible. Fluctuations in total annual lamb losses were due primarily to declines or increases in predation.

The economic analysis was based on estimates of total predation loss. Even with current predator control programs, an average sheep ranch in the region suffered an estimated annual lamb loss of $1,856. Migratory range herds typical of those sampled averaged from $2,758 to $3,493 annually in predator losses. In addition, indirect regional losses could average as high as $454,000 annually—a severe detrimental impact on both the individual sheepman and the rural community.

Sound public policy concerning predator control must be based on continued investigation of the complex relationships between predator population, predator control activities, and livestock losses to predation. Hopefully, the data and analysis presented will be helpful in resolving some of the many issues in predator management.

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Alkaloid Levels in Reed Canarygrass Grown on Wet Meadows in British Columbia

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Abstract

Hordenine, gramine, and 5-methoxy-N-methyltryptamine (5MMT) were identified as the major basic alkaloids in reed canarygrass grown on wet meadows in Interior British Columbia. The concentrations of these anti-quality constituents, determined sequentially at four field locations, were exceptionally low compared with levels found for reed canarygrass grown under growth room conditions. Under field conditions, for example, 5MMT levels did not exceed 250 μg/g (dry wt), whereas a peak level of 4,250 μg/g 5MMT was recorded from the growth room. Depressed alkaloid levels under wet meadow field conditions were observed in all varieties tested including two experimental varieties, one registered variety, and a commercial type. Low alkaloid levels on wet meadows appeared to coincide with fewer types of alkaloids: 5-methoxy-N, N-dimethyltryptamine (5DMT) was not detected under field conditions but it was present in all reed canarygrass samples analyzed from the growth room. Field applications of fertilizer (NPK) appeared to have marginal effects on alkaloid levels. On wet meadows the trends indicated that gramine and 5MMT concentrations increased toward the end of the growing season, but low total alkaloid levels were still maintained. The factor of soil moisture stress is reviewed in relation to alkaloid levels in reed canarygrass. Recently developed thin layer chromatography (TLC) scanning procedures were used to determine concentrations of gramine and 5MMT. New TLC fluorescence methods were devised for the quantitative determination of hordenine and 5DMT in reed canarygrass.

In the British Columbia Interior, large wet meadow areas composed primarily of low-yielding native sedge-grass mixtures are being reseeded to reed canarygrass (*Phalaris arundinacea* L.) (van Ryswyk et al. 1974; van Ryswyk and Bawtree 1971). Organic soil meadows and bogs in particular are becoming a principal source of reed canarygrass hay in the central Cariboo region. The aftermath is grazed by cattle in late summer and fall. Ruminants grazing reed canarygrass can be debilitated, however, when the forage contains high concentrations of basic alkaloids. Marten et al. (1976) demonstrated that average daily gains were reduced and the incidence of diarrhea increased when sheep and cattle grazed high-alkaloid (0.19 to 0.68% dry wt) as compared with low-alkaloid (0.06 to 0.32%) genotypes. The poor performance related in part to differences in reed canarygrass palatability which was highly negatively correlated with the total basic alkaloid concentration (Marten et al. 1973; Simons and Marten 1971). The effects of high alkaloid diets were reversible, however, and permanent detrimental disorders were not observed (Marten et al. 1976). In contrast, the basic alkaloids of *Phalaris aquatica* (*P. tuberosa*) have been linked to the occurrence of acute "phalaris staggers" in sheep (Gallagher et al. 1964; Rendig et al. 1976). Clearly the phalaris alkaloids can depress animal performance and therefore they are considered to be anti-quality constituents.

The above studies have emphasized the anti-quality effects of four indole alkaloid constituents: N,N-dimethyltryptamine (DMT), 5-methoxy-DMT (5DMT), gramine and 5-methyl-6-methoxy-1,2,3,4-tetrahydro-β-carboline. The role of two additional alkaloids, 5-methoxy-N-methyltryptamine (5MMT) and hordenine (a phenolic alkaloid) has been obscured in part by a lack of sensitive and specific methodology[1] (Coulman et al. 1977). Similarly, technical difficulties have discouraged a quantitative study of the concomitant variation of individual reed canarygrass alkaloids. The presence of tryptamine alkaloids, for example, interferes with the colorimetric determination of gramine and/or hordenine[1] (Woods and Clark 1971). Specific fluorometric scanning methods have been developed recently for the quantitative determination of reed canarygrass indole alkaloids (Majak and Bose 1977; Majak et al. 1978). In the present work we have expanded the procedures to accommodate the simultaneous determination of 5DMT and 5MMT, and a specific fluorometric scanning procedure has been developed for the quantitative determination of hordenine as the dansyl derivative. Accordingly, it was feasible to (a) monitor sequentially the specific alkaloid levels of reed canarygrass stands on four Interior Organic meadows in B.C., (b) to examine some variety differences with respect to individual alkaloid levels and (c) to compare the wet meadow field values to growth room levels where much higher alkaloid concentrations were produced. In effect, this survey will reveal the current status of anti-quality components in reed canarygrass grown on B.C. Interior Organic meadows.

Materials and Methods

Experimental Sites and Varieties

Reed canarygrass stands were located at Strachan Lake (elev. 1,460 m), Watch Lake (1,190 m), Hopkinson's Meadow (1,250 m) near LacLeJeune, 134 Mile House (750 m) and Horse Lake (930 m). These sites were situated over a distance of 200 km between Kamloops and Williams Lake. The soils were classified as Mesisols (Hemist) for the first three meadows, Humisol (Saprist) for the fourth, and Humic Gleysol (Aquoll) for the fifth, according to the system of the Canada Soil Survey Committee (1974) and the U.S. soil taxonomy system (U.S. Dep. Agr. 1975).

Two experimental varieties, NRG 721 and NRG 741 ("low tryptamine" and "high tryptamine" respectively) and a registered

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[1] Personal communication, D.L. Woods, Agriculture Canada, Saskatoon, Sask.

variety, Castor, were established at Hopkinson's Meadow and under growth room conditions in Kamloops. A commercial seedlot of known origin was also cultured in the growth room. The origins of the commercial seedlots established on the remaining meadows were unknown. A standard peat-sand mix in pots (B.C. Ministry of Agr. 1972), a 21° C room and soil temperature and a 13-hr photoperiod were used in the growth room. The light source was fluorescent lamps (Vita-Lite, Duro-Test Corp.) generating approximately 150 cal/cm²/-day at the average height of the grass.

Plant Samples

Composite samples of reed canarygrass (100 g fresh wt unclipped, aerial portions) were harvested sequentially from a 3 × 8.4-m plot at each meadow, transported on ice, and frozen. A measure of the variability within a plot was obtained by dividing each plot into 1.5 × 2.1 m quarters and a 25 g fresh wt sample from each quarter was collected for alkaloid analysis. Each frozen sample was chopped finely in a coldroom (2° C), a 10-g subsample was tared for extraction, and duplicate subsamples were used for dry wt determinations. Since the extraction procedure was complete (as evidenced by chromatographic checks of serial extractions) and since there was close agreement between duplicate extractions (<±5% variation with respect to duplicate alkaloid determinations), a single extraction of each sample was found to be sufficient.

Quantitative Determinations

For gramine, 5MMT, and 5DMT determinations, a frozen 10-g portion was extracted, fractionated, and two-thirds of the final chloroform extract was washed with water, concentrated to dryness, and redissolved in 0.25 mℓ 2-methoxy-ethanol (extract A) as described previously (Majak and Bose 1977). For hordenine determinations the water wash was omitted from the remaining one-third portion of the chloroform extract, and this was concentrated to dryness and redissolved in 0.5 mℓ 2-methoxy-ethanol (extract B).

Microliter aliquots of extract A were applied to precoated TLC plates for quantifying gramine and 5MMT by fluorometric scanning (Majak and Bose 1977; Majak et al. 1978). Samples which contained both 5MMT and 5DMT were resolved in a new chromatographic system which permitted the quantitative determination of both compounds on a single plate by acid-induced fluorescence as follows: A silica gel 60 plate (E. Merck, Darmstadt, EM No. 5763) was exposed to HCl fumes for 15 min. Following the exposure, aliquots of extract A and reference standards were applied, the plate was developed in isopropanol:ethyl acetate:conc. HCl, 60:15:1, and dried in a fume hood for 10 min in a uniform current of air away from direct light. 5MMT (R_f 0.32) and 5DMT (R_f 0.10) were located by their bright yellow fluorescence under short-wave ultraviolet light and immediately scanned at right angles to the solvent flow using the fluorometer conditions described previously (Majak and Bose 1977). When an authentic sample of 5DMT was subjected to the above fractionation procedure, the compound was recovered in 95% yield.

The procedure for hordenine determination was as follows: Extract B, 200 $\mu\ell$, was concentrated to dryness in a 0.3 mℓ Reacti-vial and securely capped using a Tuf-Bond disc (Pierce Chem. Co. No. 12712). The dried residue was dissolved by injecting 100 $\mu\ell$ acetone and this was followed by injections of 100 $\mu\ell$ 0.1 *N* $NaHCO_3$ and 100 $\mu\ell$ dansyl chloride reagent (prepared fresh daily by dissolving 15 mg dansyl chloride in 5ml acetone and stored in the refrigerator). The vial was heated for 30 min at 30°C in the dark, then chilled in a freezer before applying microliter aliquots to a silica gel 60 plate (EM No. 5763) with adjacent dansyl-hordenine standards. The TLC plate was developed in freshly prepared PENE solvent (Majak et al. 1978) and dried for 60 min in a fume hood, minimizing exposure to light. The dansyl-hordenine spots (R_f 0.75), located by their yellow fluorescence in short-wave ultraviolet light, were scanned at right angles to the solvent flow using the fluorometer conditions described previously (Majak et al. 1978) but employing a No. 8 (Turner No. 110-817) secondary filter. The relationship between peak height and dansyl-hordenine concentration was linear over the range 0.05 to 0.5 μg hordenine. When an authentic sample of hordenine (100 μg) was added to the crude plant extract, the above procedure recovered hordenine in 97% yield. With samples containing high levels of 5MMT (>500 μg/g dry wt) a 10- to 20-fold dilution of extract B was required to ensure the presence of excess dansyl reagent.

Results and Discussion

Alkaloid Profiles

The alkaloid screening experiments conducted during 1977 confirmed our previous observation (Majak and Bose 1977) that gramine, hordenine and 5MMT are the primary basic alkaloids in reed canarygrass grown on Organic soil meadows in Interior British Columbia. The alkaloid profile of reed canarygrass grown on the Gleysolic soil meadow (Horse Lake) was similar (Table 1), and 5MMT appears to be the major component of the unidentified tryptamines reported for the Thompson River meadow (Parmar and Brink 1976). Growth room samples contained an additional alkaloid, identified as 5DMT on the basis of fluorescence and co-chromatography with authentic 5DMT in a number of solvent systems on cellulose and silica gel TLC. Tetrahydro-β-carboline derivatives and DMT were not detected in the present studies.

Table 1. Mean concentrations (μg/g dry wt) for 5MMT, gramine and hordenine in reed canarygrass subcomposite field samples.

Site	Collection date 1977	Plot no.	Alkaloid 5MMT	Gramine	Hordenine
Strachan L.	Aug. 11	1	33 a[1]	115 a	240 b
134 Mile	Jul. 21	1	29 a	62 a	103 c
Watch L.	June 21	1	14 a	77 a	190 b
		2	29 a	80 a	373 a
Horse L.	June 21	1	24 a	67 a	359 a
		2	38 a	52 a	253 b
Means of experimental plots			28 C	75 B	253 A

[1] Means sharing the same letter within a column (lower case) or within a row (upper case) did not differ significantly according to Duncan's new multiple range test ($P = .05$). Each mean is derived from the alkaloid concentrations in four subcomposite samples. a subcomposite samples was a random 25-g-fresh-wt portion from each plot quarter.

Parmar and Brink (1976) suggested that the tryptamines of reed canarygrass could be implicated in a pasture-mediated form of bovine pulmonary emphysema prevalent throughout Interior British Columbia and the intermountain states. Intraruminal administration of indole derivatives such a tryptophan and indole acetic acid will induce pulmonary emphysema and edema in cattle and the active metabolite, dissimilated by ruminal microorganisms, has been identified as 3-methylindole (Carlson et al. 1972). Yokoyama and Carlson (1974), however, showed that for a number of indole compounds, including tryptamine and 5-hydroxytryptamine, microbial degradation to 3-methylindole does not occur, and whether indoles such as 5MMT, 5DMT, or gramine are potential substrates for 3-methylindole formation remains to be seen.

Variability in Alkaloid Concentration

Alkaloid identification at each site was followed by a series of replicate determinations to give an indication of the variability in alkaloid concentration within each experimental plot. A knowledge of the potential variation within a site would provide a basis for comparing sequential alkaloid values. Table 1 lists the means for 5MMT, gramine and hordenine derived from subcomposite samples at three Organic and one Gleysolic meadow. A high degree of variability is indicated within each experimental plot and, in the case of hordenine, between replicate plots at two sites (Table 1). The variability could be

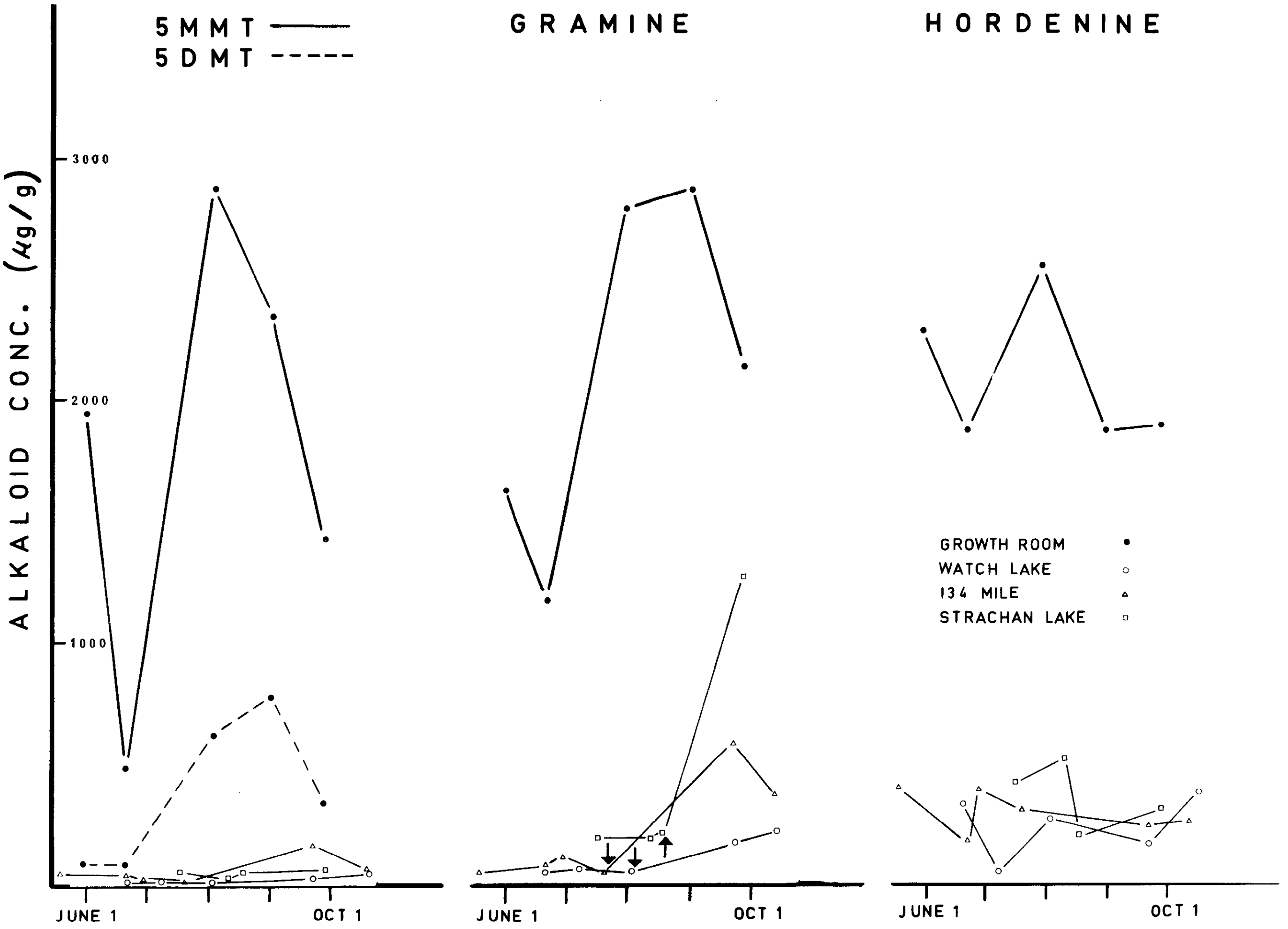

Fig. 1. *Alkaloid levels (µg/g dry wt) in commercial reed canarygrass* established at three wet meadows (solid symbols) and in the growth room (solid symbols) during 1977. Date of harvest on meadows indicated by arrows.*

related to differences in plant nutrient uptake as affected by variations in depth to water table and inherent soil fertility differences within plots.[2]

The gramine and hordenine values reported in Table 1 are exceptionally low in comparison to previously reported figures. A survey of reed canarygrass introductions conducted by Coulman et al. (1976), for example, yielded mean gramine concentrations of 2,090 µg/g dry wt (range 40 to 6,910 µg/g) and 2,200 µg/g (range 170 to 11,510 µg/g) over a 2-year study. On the other hand, clones selected for low gramine yielded average values of 190 µg/g gramine and 1,220 µg/g hordenine (Coulman et al. 1977), but these values are still in excess of our means shown in Table 1. Summation of the individual alkaloid values in Table 1 reflect a total basic alkaloid content of 0.02 to 0.05%, a range that would be considered lower than previously reported low alkaloid levels (Marten et al. 1976; Hovin and Marten 1975). The low 5MMT values in Table 1 are in agreement with our previous analyses of reed canarygrass samples from Organic meadows in 1976 when the observed range was 14 to 67 µg/g (Majak and Bose 1977).

Changes in Alkaloid Levels During the Growing Season

The next step was to sequentially monitor alkaloid levels on meadow sites and to observe possible fluctuations during the growing season. Figure 1 illustrates the results of this study at three meadows where reed canarygrass had been established from commercial seed. Low concentrations of 5MMT, usually <60 µg/g dry wt, were maintained throughout the growing season. Low gramine levels (<125 µg/g at Watch Lake and 134 Mile) on the other hand were elevated in the regrowth herbage after harvesting but a similar response was not observed from hordenine. Excluding the September gramine value for Strachan, the trend of seasonal plot means was hordenine<gramine->5MMT and a similar trend was observed at Hopkinson's Meadow (Fig. 2). Depressed values for 5MMT, gramine, and hordenine were recorded at Hopkinson's Meadow in all varieties tested (Fig. 2). Under growth room conditions, however, not only were the levels of 5MMT, gramine, and hordenine substantially elevated but 5DMT made an appearance for the first time (Fig. 1 and 2). Higher 5DMT levels were observed in the experimental variety NRG 741 and in the commercial type (Fig. 1 and 2), as compared with NRG 721 and Castor (not illustrated), which gave peak 5DMT values of 300 µg/g and 150 µg/g, respectively. Summation of the peak alkaloid levels produced under growth room conditions gave a total alkaloid content of 0.84% for the commercial type (Fig. 1) and 0.96% for the experimental variety NRG 741 (Fig. 2). These values could be considered debilitative (Marten et al. 1976) but not excessive since Simons and Marten (1971) have reported a total basic alkaloid range of 0.01 to 2.75% for reed canarygrass clones. Therefore the outstanding feature recorded in Figures 1 and 2 is not so much the increased level in the growth room environment as the suppressed level and fewer types of alkaloids in wet meadow field situations.

[2] van Ryswyk, A.L., 1977. Unpublished results.

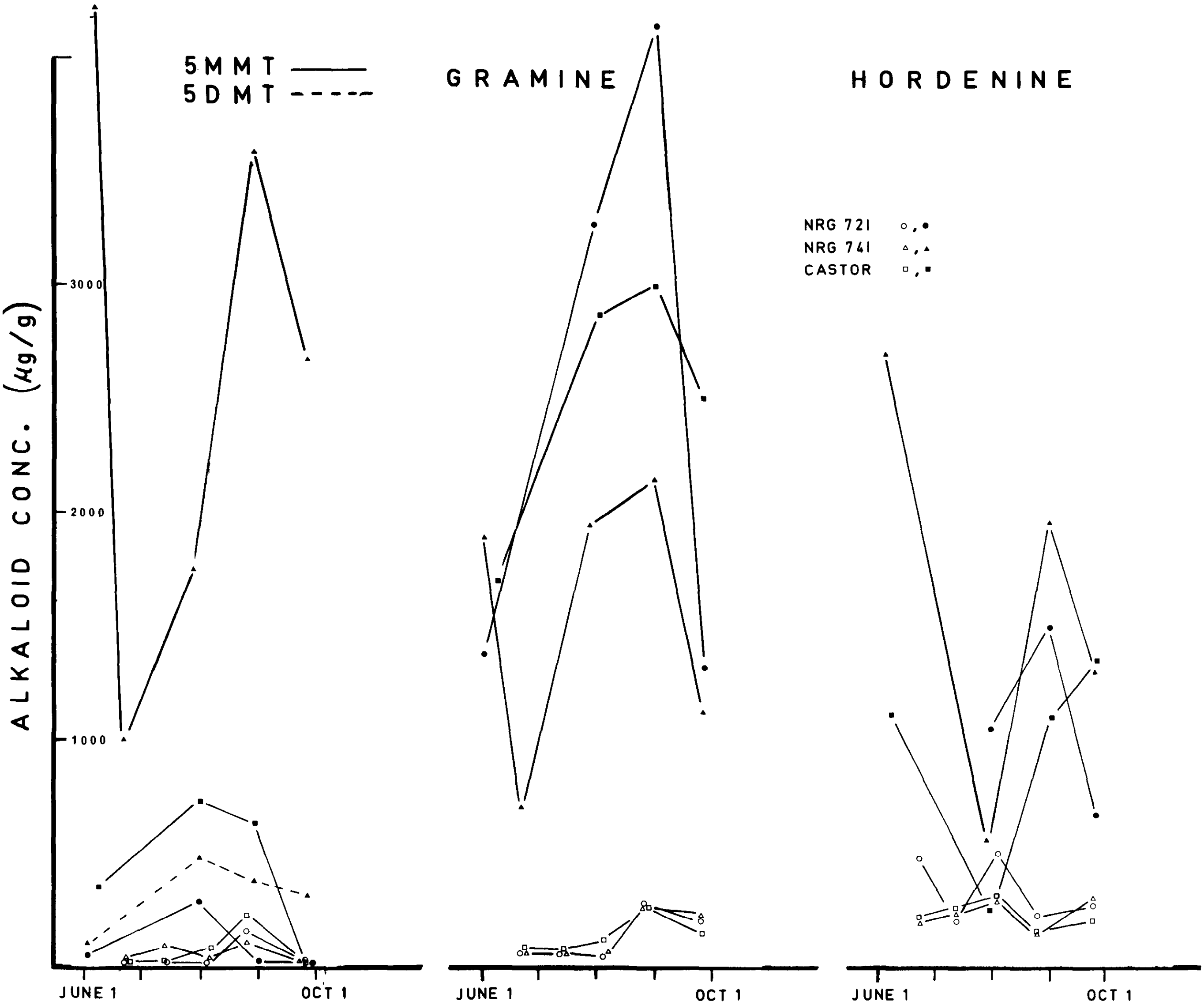

Fig. 2. *Alkaloid levels (μg/g dry wt) in three varieties of reed canarygrass at Hopkinson's meadow (open symbols) and in the growth room (solid symbols) during 1977.*

The low alkaloid accumulation on wet meadow sites cannot be attributed exclusively to deficiencies in soil fertility. In fact, Marten et al. (1974) demonstrated higher alkaloid levels in reed canarygrass grown on infertile peat as compared with fertile mineral soils. Where nutrient amendments have elevated alkaloid levels in reed canarygrass, the changes have been relatively small. A six-fold increase in NH_1NO_3 application (from 50 to 300 kg/ha N) for example, produced only a 13% increase in total tryptamines (Parmar and Brink 1976). Similarly, application of complete fertilizer and additional nitrogen (240 kg/ha N) to an infertile peat soil resulted in a minor change in total alkaloids as the level increased from 0.05 to 0.07% (Marten et al. 1974). Furthermore, we compared alkaloid levels in reed canarygrass growing on fertilized wet meadow plots which had received an original application of 150 kg/ha N (NH_4NO_3), 100 kg/ha P, and 200 kg/ha K, followed by mid-season application of 150 kg/ha N. The results indicated that only in 6 out of 30 cases during the growing season was an alkaloid concentration at least doubled in comparison to reed canarygrass samples from unfertilized plots. For example, on fertilized plots 5MMT and gramine increased to maximum levels of 164 μg/g and 1,806 μg/g, respectively (Strachan Lake, Sept. 29); and hordenine increased to 625 μg/g (Watch Lake, June 21). These levels are still well below the high-alkaloid range generated in the growth room.

Marten (1973) observed that increased alkaloid levels in reed canarygrass are produced in response to moisture stress and concluded that of all the environmental parameters tested in relation to alkaloid accumulation the most critical was soil moisture availability to plants. The corollary suggests, therefore, that in reed canarygrass alkaloid biosynthesis could be diminished under optimal moisture conditions. A continuous store of soil water available to plants under negligible soil moisture tension typifies the saturation conditions of Organic soil meadows. In this situation one would expect reed canarygrass to be under minimal moisture stress. In the absence of rainfall in late summer and early fall the depth to water table on wet meadows can increase, but the availability of water is maintained usually by upward capillary movement. Trends reflect increasing indole alkaloid (5MMT and gramine) concentrations toward late summer (Fig. 1 and 2) and whether this is in response to an increase in moisture stress remains to be seen. Previously, we reported a range of values for gramine (280-780 μg/g in the Castor variety established on Solonetzie soil (Majak et al. 1978). This saline situation features a soil moisture stress situation for plants that could be reflected in the elevated alkaloid levels. Further research will reveal whether moisture availability can control alkaloid accumulation in reed canarygrass.

In conclusion, factors which could enhance alkaloid biosynthesis in the growth room should be considered and these include reduced light energy and rapid vegetative regrowth in response to clipping. Artificial shading experiments have demonstrated a dramatic rise in DMT and 5DMT concentrations when *P. tuberosa* was exposed to <34% full sunlight (Moore et al. 1967). Similarly, total basic alkaloid concentration in reed canarygrass increased by over 50% in response to shading (Marten 1973). Light energy in our growth room was measured as approximately 150 cal/cm^2/day; or 25% of full sunlight on a summer day at latitudes where meadows were studied[3]. Clipping reed canarygrass every 2 weeks produced a sharp increase in indole alkaloid levels as compared to levels in free growth tissue (Woods and Clark 1971). Growth room samples in our experiments were harvested approximtely every 5 weeks and a similar response resulting in high alkaloid production is not unlikely.

[3] Personal communication, R.J. Williams, B.C. Ministry of the Environment, Kamloops, Kamloops, B.C.

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TECHNICAL NOTES

Southern Wax-myrtle Response Following Winter Prescribed Burning in South Florida

STEVE W. TERRY AND LARRY D. WHITE

Abstract

Southern wax-myrtle is an undesirable shrub that is invading thousands of acres of rangeland in south Florida. Prescribed burning has been considered a potential management tool for maintaining pastures free of wax-myrtle. Results of this study show wax-myrtle to be easily crown killed by a single winter fire. However, most plants survive through basal sprouts. Use of prescribed winter fire to reduce wax-myrtle competition will require repeated periodic burns coordinated with cattle grazing programs.

Senior author is research biologist, Range Ecosystem Management, University of Florida, Gainesville. Larry D. White is currently range extension specialist, Texas A&M University, Uvalde. At the time of the study he was associate professor, Range Ecosystem Management, University of Florida, Gainesville.
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Southern wax-myrtle (*Myrica cerifera* L.) is a small, aromatic, evergreen shrub or tree common throughout the coastal plain of the southeastern United States (Grelen and Duvall 1966; Kurz and Godfrey 1962). Southern wax-myrtle is rapidly invading many ranges throughout southern Florida. McCaleb (1970, personal comminication) estimated two million acres of south Florida already invaded, and soon to "become shaded to the point that forage production will be reduced to the extent that major pasture renovation will be required." The noticeable increase in wax-myrtle is most common on areas where prescribed burning is not used as a periodic management practice. Grelen and Duvall (1966) reported that wax-myrtle plants survive burning by resprouting vigorously from the root collar. "Plants burned periodically average about 3 feet high, forming large, many-stemmed clumps." Similarly, Givens (1962) observed that burning can be used effectively to prevent encroachment of myrtle on beach

Fig. 1. *Typical unburned wax-myrtle scattered through a saw-palmetto-creeping bluestem (*Schizachyrium stolonifer *(Nash.) Hitch.) pasture.*

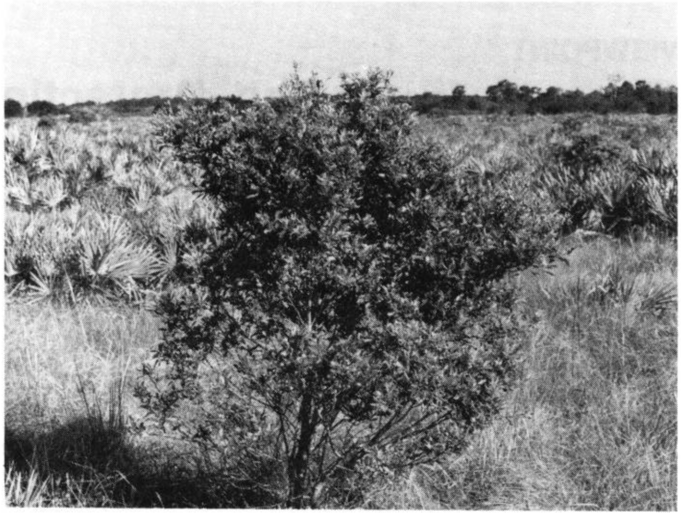

Fig. 2. *Canopy killed wax-myrtle with numerous basal sprouts one growing season after a winter prescribed burn.*

marshes. Langdon (1971) reported single summer fires killed less than 10% of bayberry (probably *Myrica pennsylvania* Loisel.); however, 100% kill was achieved after seven annual summer burns. He concluded that "hardwood vegetation recovers to its previous state from a single summer or winter burn in 5 to 7 years." Lotti (1950) found that four annual summer fires in South Carolina pine forests resulted in effective control. Kill was 5%, 35%, 48%, and 90% with one summer fire, two successive summer fires, three successive summer fires, and four successive summer fires, respectively. Lewis and Harshbarger (1976) found after 20 years of prescribed burning in South Carolina that southern wax-myrtle crown spread (m) per 25-m transect was 1.0, 0.8, 2.0, and 0.03, 0.24, and 0.0 for unburned control, periodic ("burned when 25% of certain hardwood stems reached 5 cm dbh") winter, periodic summer, annual winter, biennial summer and annual summer, respectively. The annual winter fires significantly reduced wax-myrtle canopy while periodic winter fires did not. Results from winter burning of wax-myrtle in south Florida have not been observed in the literature.

This study was initiated to determine the amount of control winter prescribed burning has on southern wax-myrtle on flatwoods sites in south Florida.

Methods and Materials

The study was conducted at the Agricultural Research Center, Ona, Fla. Six range pastures heavily infested with wax-myrtle were prescribed burning during January and March 1974. The pastures were approximately 16 ha in size on typical south Florida flatwoods. These pastures had not been burned for at least 10 years (Fig. 1). Associated shrub species included dense stands of saw-palmetto (*Serenoa repens*) Lodd. ex Schultes) and some gallberry (*Ilex glabra* (L.) Gray). Back fires were used until a sufficient fuel break was established, then the entire pasture was encircled and a head fire allowed to burn.

Burned areas were sampled for number of live and dead shrubs, estimated percent canopy kill, and number of shrubs with basal sprouts along randomly located 3.0 m wide belt transects the length of each pasture. The number of transects varied according to pasture configuration to include a 10% area sample from each pasture. Any part of a shrub encountered by the belt transect was considered as a hit. Sampling was completed in October 1974. The six pastures were used as replications to develop confidence intervals.

Results

The average density of wax-myrtle shrubs was 27 ± 11 ($P>0.05$) per ha over the six pastures. Most wax-myrtle were approximately 4 to 5 m in height scattered through each pasture. Only $5.4\pm1.4\%$ of these shrubs survived the fire with little if any visible damage. Most of these live shrubs occurred near the edge of the pastures and around several ponds located within the burns. The remaining shrubs were either killed outright ($8.4\pm1.8\%$) or remained alive through basal sprouts $86.2\pm15.5\%$).

Discussion and Conclusions

Kill of wax-myrtle with one winter prescribed burn was similar to that reported for summer fires in South Carolina (Lotti, 1956). Single prescribed fires are apparently very effective in top-killing wax-myrtle (Fig. 2); however, periodic fires would be necessary to maintain reduced canopy. Periodic burns should be designed to increase kill for a number of years then become less frequent. Timing of periodic burns based on recovery rate of "certain hardwoods" to a 5 cm dbh as per Lewis and Harshbarger (1976) would not be recommended if greater plant control is desired. Canopy removal would allow more sunlight for understory herbage and probably reduce competition from wax-myrtle. In addition, Grelen and Duvall (1966) suggested that frequent burning and subsequent browsing by cattle and wildlife keep wax-myrtle low in stature. Browsing usually occurs during January and February on burned areas. Unburned wax-myrtle receives little utilization. Prescribed burning coordinated with grazing management programs appears to be essential for maintaining low stature wax-myrtle pastures in south Florida unless more expensive mechanical control techniques are employed.

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VIEWPOINT

Comments on the Protection of an Endangered Species

PATRICK C. JOBES

Throughout much of the Rocky Mountain West, an endangered species, the rancher, struggles for his survival. Struggle for survival is hardly new to ranchers. They have endured long, cold winters, dry summers, predators, and declining wool and beef markets. These elements have taken their toll but in many pockets of the Rocky Mountain West, ranchers continue to occupy essentially the same niche as they have since World War II or, for that matter, since the turn of the century. Their means of adaptation have been slightly modified. The speed and power of their geographic mobility have increased, their dens have become plusher, their operations in their habitat have increased in scale but their niche still remains much as it has been for nearly a century.

A transplanted species that was largely responsible for the near extinction of indigeneous species occupying the territory prior to their invasion, the rancher appeared to be peculiarly well adapted to its habitat. However, recent threats have begun to threaten many of the species. In particular, usually relatively isolated, locales competition between ranchers and other human species has caused some alarm to environmentalists and to administrators responsible for the protection of this and other species. The questions which these concerned persons most confront are first, whether it is possible for this species to survive these threats and second, whether the costs of ensuring survival can be justified in terms of the considerable costs which may be expended for their preservation.

Recent research in the natural habitat has led to several observations and generalizations. In lieu of the potential extinction of the species such recording is essential for knowledge available to future generations. Moreover, it is hoped that such observations will prove of scientific merit for related research.

The Rocky Mountain rancher does not appear to have any especially advantageous biological characteristics which can account for adaptation to its environment. His size and intelligence appear to be similar to other sub-species of humans. His color is disproportionately light, although early population movements among this light-skinned variety probably were more of a function of his historical idiosyncracies than of peculiar adaptive advantages among this sub-species. His current foliage, which shows little seasonal variation, appears to have evolved from earlier adaptive characteristics which have become dysfunctional elsewhere. Among these characteristics are pointed toed feet elevated at the heel, stove-piped, frequently bowed legs, and broad brimmed heads. So common are these characteristics that the rancher might become known as the broad-brimmed, pointed-toed sub-species.

Although the appearance of most Rocky Mountain ranchers is well defined, their activities can be differentiated. Predominantly specializing in the domination of more submissive animal varieties, many ranchers also participate in other subsistence activities. Many have been observed altering natural waterways, gathering and storing feed for the winter through a variety of mechanisms. They further have been observed spending inordinate amounts of time in brief migrations in four wheeled vehicles with open boxes.

Ranchers had appeared to be successfully adapted to their environment until recent years. Their domination of the environment and competing sub-species indicated that their adaptive characteristics of rugged individualism, tight lippedness, and geographic isolation, might well permanently sustain them. However, these characteristics, so adaptive in earlier periods appear dysfunctional against new varieties of competition. Recent competitive sub-species with different adaptive skills appear likely successors to ranchers where such new skills are effectively used. These new skills, rugged collectivism, oral effusiveness and massive proximics, make their intentions for new occupation for the area appear likely. Thus, vestigial rancher characteristics so adaptive for the ranchers during the earlier period of stable agricultural land use appear to be obsolete for preventing conversion of land to other uses. In fact, these obsolete characteristics seem to guarantee that new and different successors will replace the ranchers, who, being incapable of organization or communication even for the purposes of the survival within their niche, are easy foes.

During recent years all sub-species have been subject to severe competition, in light of the environmental perils mentioned earlier, with other species. In particular, the sub-divider and the consolidator (agribusiness) have successfully preyed upon or succeeded ranchers of most sub-species. This succession alone deserves discussion elsewhere. However, a new competitor, the energy developer, recently has threatened the habitat of many ranchers. This competition and its probable impacts pose the greatest threat yet experienced by the rancher.

Many readers may object to the foregoing discussion because of its deliberate depersonalization of rural ranch society. At issue, though, is whether the society should be preserved and, if it should be, then how it should be done. The characteristics of rural ranch society make its continued existence unlikely in areas where land values exceed the potential agricultural profit from the land. Massive mining, recreational development, and residential development constitute competition to the agricultural use of land and, consequently, to the life style that emerged from such use. The impersonal discussion merely suggests that persons in agriculture in relatively natural settings have a vulnerability to imposed change from other uses. The analogy between rural ranch society and endangered animal species is ironic, though, because in many cases the animals enjoy greater protection than do the humans. Humans are felt to be capable of readapting to their altered environments as indeed they are. Even the ranchers most adamantly opposed to development will not die from development. But, their way of life will case to exist as they lose in the competition for their land.

Federal and state governments are well aware of the issues involved in displacing persons in order to permit new uses of the land. Most displacement occurs with acquiescence, if not jubilation, toward proposed developments. Most ranchers appear to be strongly opposed to the changes affecting local lands and their lives. In spite of their opposition to such changes most legal arguments regarding development center around the probabilities of land reclamation, air and water pollution and similar effects on the physical environment. Somehow this emphasis of placing the physical environment in a more primary position than the social environment seems topsy-turvy. The way of life and the feelings of persons are the genuinely unique characteristics of humans and these are the characteristics which have emerged as most negotiable or ignored when decisions on land use are made. After all, among humans it is the manner in which life takes place rather than mere survival which distinguishes from other species. Certainly the variety of life styles deserves protection as much as do the lives of lesser species.

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